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ZONAL DISTRIBUTION OF ORE DEPOSITS IN CENTRAL EUROPE.*

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THE zonal distribution of ore deposits around batholiths is a matter of much interest and discussion among American mining geologists. W. H. Emmons, W. Lindgren, J. E. Spurr, and many others have been employed with this theory during recent years. In England the zonal distribution was especially emphasized by R. H. Rastall in his textbook and in several separate papers. On the European continent some short papers and occasional notes discuss the problem, but in general the zonal theory was not used as a leading point of view in the discussions and textbooks on mining geology. DeLaunay[1] only, who based his observations on the ore deposits of France, came near to the modern theory.

It is not by chance that science in Central Europe went this way. The relation of ore deposits to intrusive rocks is far less intimate in Central Europe than it is in America or in England, where especially the tin lodes of Cornwall really forced the geologists to see things from the standpoint of zonal distribution. In Germany, Austria, Hungary, and Switzerland, the relation between ores and intrusives is so complicated that scientists formerly laid a stronger emphasis on the relation between ores and wall rocks, which is often very clearly shown in the mines.

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[1] F. Fuchs et L. DeLaunay, "Traitè des gîtes mineraux et metalliferes," Paris, 1893.

Therefore, during a score of years Sandberger's theory of lateral secretion found many friends, especially among theoretical geologists, who were not closely connected with mining practice. Ascensionists at the mining academies, secretionists at the universities, that was almost the rule in Germany at the end of the last century. In some districts, however, the relation between ores and intrusives had already been observed; *e.g.*, by Lossen [2] in the Harz, and by Reyer [3] and Dalmer [4] in the Erzgebirge.

If we compare on a geological map of Central Europe the distribution of ore deposits and granitic intrusions, we will find them clearly connected in the western and southern Erzgebirge, less clearly in the Harz, and traces of connection in Lower Silesia, though in Lower Silesia the scarcity of ores and the abundance of granites disturbs the view. But some ore districts of large

FIG. 1. Map of the principal batholiths and ore deposits of Central Europe. Dotted line shows area of young sediments of the great plains.

[2] K. A. Lossen, "Erlauterungen zur Geol. Spezialkarte von Preussen," Lief. 16, *Bl. Harzgerode*, p. 84–89.

[3] E. Reyer, "Zinnerzführende Tiefeneruptionen von Altenberg und Zinnwald," *K. Oesterr. Geol. Reichsanst*, 1878; idem, *Geologie des Zinnes*, 1881.

[4] K. Dalmer, "Der Altenberg-Graupener Zinnerzlagerstätten distrikt," *Zeitschr. prakt. Geol.*, 1896, p. 148.

extension and great economic value, as in Rhenania and Upper Silesia, are far from any intrusive batholith. In some of the German and Austrian literature of former years we find a remarkable misunderstanding of the connection between ores and "eruptives"; and small dikes of diabase, lamprophyre, or porphyry were emphasized as of much genetic interest, and therefore the connection with large intrusive masses was not recognized.

In Central Europe we find three periods of intrusive activity that are all connected with orogenesis.

(1) The Caledonian in Silurian and early Devonian time. The intrusives of this time are mostly parallel-textured and gneissic rocks. Large extrusions of diabase and of keratophyre are found in later Devonian.

(2) The Carboniferous intrusives are of late Carboniferous age and were followed by extrusions of porphyry and basic rocks (melaphyre) in the Lower Permian. Nearly all ore deposits that are clearly related to intrusives belong to this period, except those in the southeastern part of Central Europe in Hungary and Transylvania.

(3) The Tertiary volcanics are extrusives or volcanic necks: basalt, phonolite, trachyte, and in the Carpathians andesite. Only a few areas of hypabyssal rocks show us that there are intrusives of this period at greater depths, but are not yet exposed by erosion. Ore deposits belonging to this period are scarce and are only abundant in the Carpathians, especially in Transylvania.

The chief districts of uncomplicated Carboniferous metallogenesis are the Saxon Erzgebirge and the Harz. The tin lodes and tin impregnations of Altenberg, Zinnwald, Schellerhau and so on are clearly related to granitic intrusions, but these intrusions, though all of them are Carboniferous and all are without gneissic structure, are of slightly different ages, and it is only the youngest granite, younger even than a granitic porphyry, which has caused the tin-ore deposits. Reyer assumed that the "tin granites" form stocks of very small extension and are the latest acid extracts of a huge mass of granite in abyssal depth, from which were

derived at an earlier stage the larger granites devoid of tin and at a later stage hypabyssal masses and dikes of granitic porphyry. Emmons [5] in his new nomenclature would call them acrobatholithic, but main emphasis should be laid on the late time of the metallogenesis rather than on the position near tops of batholithic intrusions.

At the village of Seifen, as in Cornwall, the tin lodes turn to cupriferous lodes in their upper parts, but these cupriferous deposits are rich in silver. At Sadisdorf the tin lodes are rich in molybdenum, bismuth, and sulphur-minerals, and farther away from the intrusive, upward as well as outward, the lodes, according to Schwartz,[6] become "kiesig-blendig," *i.e.*, they carry pyrite, arsenopyrite, chalcopyrite, sphalerite, and galena. The intrusive at Sadisdorf is not a true granite but a granite porphyry.

FIG. 2. Map of the principal batholiths and ore deposits of the Saxon Erzgebirge.

[5] W. H. Emmons, "Relations of Metalliferous Lode Systems to Igneous Intrusives," Am. Inst. of M. Eng. Pamph. No. 1571, I.

[6] Schwartz, "Die Zinnerzlagerstätten im Gebiet von Niederpöbel und Sadisdorf," *Jb. f. d. B. u. Hüttenwesen.*

The larger granitic intrusives in the western Erzgebirge at Schneeberg, Annaberg, and Marienberg are also connected with lodes of tin and tungsten ore, but far more valuable are the lodes containing cobalt, nickel, bismuth, and uranium, mostly rich in silver. Perhaps these ores are of later deposition and less "perimagmatic" than the tin ores, but there is no difference in the location of the tin-tungsten and the cobalt-bismuth-silver deposits. So the district must be "telescoped," but it is remarkable that the uranium is found out of the granite as pitchblende but within the granite area we find uraninite, and this mineral and other phosphates also occur in the pegmatite veins. Another proof of telescoping is that typical contact metamorphic deposits have been altered by the development of minerals of hydrothermal origin. At Klingenthal-Grasslitz the masses of pyrite and pyrrhotite are veined by chalcopyrite, and near Schwarzenberg deposits of magnetite in the vicinity of fissure veins are impregnated with tin ore, arsenopyrite, and workable shoots of sphalerite. The scarcity of tin ores and the abundance of cobalt-uranium ores in this district seems rather to be owing to a difference in the chemical composition of the magma than to the zonal position of the deposits. At Schneeberg as well as at Joachimstal an increase of uranium and a decrease of cobalt in depth is distinguishable.

As to the surface of the great granitic batholith of the western Erzgebirge, we know that it is very irregular, in places sinking to greater depths, in places appearing at the surface in small areas. The deposits of Schneeberg, Schwarzenberg, Johanngeorgenstadt, and Joachimsthal are situated in a roof pendant dipping to the NE.; at Annaberg and Geyer the granite once more appears at the surface, reaching it in a few places, but perhaps forming a dome in depth; and a third dome probably is marked by the lode system of Marienberg. Perhaps Freiberg is situated over the top of a fourth dome. The western slope of the Eibenstock batholith is steep and nearly barren of ores. The remarkably round batholith of Kirchberg and that of Lauderbach with their well-developed zones of contact-metamorphic rocks are also void of metalliferous deposits. This absence of ore deposits is because the batholiths are steep and eroded to a considerable depth: they are hypobatho-

lithic, in the nomenclature of W. H. Emmons. A very strange thing is the granite of Bobritzsch nearly east of Freiberg. It is undoubtedly of the Carboniferous type and is without trace of parallel texture. The lead-zinc lodes of Freiberg do not extend into this granite, nor is any metallic mineralization connected with it: neither tin nor cobalt-bismuth lodes occur in its surroundings; a little molybdenum only is segregated in the fissures of the granite. It is impossible that this granite is a fifth dome on the ore-bearing batholith. Either it is an early predecessor of the Carboniferous granites, which was intruded at a time when the differentiation had not yet gone far enough to yield mineralizing solutions (like the earlier granites that immediately preceded the tin-bearing granites at Altenberg and Zinnwald) or its "mise en place" is of tectonic origin, the rock being elevated from a deep-seated barren "hypobatholithic" part of the entire batholithic system.

The argentiferous lead-zinc lodes of the Freiberg district are typically cryptobatholithic. A few lodes of this type are also found in the western part of the Erzgebirge near Schneeberg, Annaberg, and especially Marienberg as "telescoped" successors in the main cobalt-uranium deposits of these districts. The minerals of the perimagmatic family do not occur at Freiberg. Neither primary tin ores, nor tungsten, nor bismuth, nor molybdenum (except at Bobritzsch) is found there, but arsenopyrite and chalcopyrite are present and increase slightly with depth. Very well shown is the increase of sphalerite and the decrease of galena in the lower parts; this change is naturally combined with a decrease of silver content, though the relation of Pb: Ag remained nearly constant. In general the normal position of metals as given by Emmons—Sb, Ag, Pb, Zn, Cu, Bi, Au, W, Sn—is very clearly shown by the Carboniferous metallogenesis of the Erzgebirge.

Besides the pyritic lodes of lead and zinc, which comprise the "kiesig-blendige" formation that yielded the bulk of the output, there were many other sets of lodes near Freiberg. In the outer parts of the district were the veins of the "noble quartz formation." These veins were distinguished by a high content of silver, partly as native silver and silver sulphide (argentite), partly com-

bined with antimony and arsenic as ruby silver, tetrahedrite rich in silver, and a few but very rich arsenopyrite (2.7 per cent. Ag). The farthest mines at Mobendorf even contained stibnite as the prevailing ore. There can be no doubt that these ores are to be considered as the upper or outer zone in the meaning of the theory of zonal distribution.

Another "vein formation" of the Freiberg district comprises the sometimes very thick and long lodes of fluobaritic ores, *i.e.*, a well-banded alternation of barite, light-colored fluorite (never the violet fluorite of tin veins) galena, a little sphalerite, pyrite, and sometimes marcasite. These veins strike differently than the quartzose veins of the kiesig-blendige formation, are distinctly younger than these, and it is highly probable that they are of Tertiary age, as shown by the fact that baritiferous veins also occur in the adjoining area of Upper Cretaceous sandstones. The silver content of the galena of these lodes, some of which are as thick as 12 feet and as long as 5 miles, is much lower than in the older veins, but it is increasing with depth. We may assume that the fluobaritic veins, as P. Krusch [7] thinks, are the youngest of a mineralization continuous from the end of the Carboniferous to at least Cretaceous time, or we may assume that they belong to a distinctly different younger metallogenesis. They are no doubt shallow-zone deposits. This inference is supported by the fact that the lead-ore deposits of Mazarron in Spain and other similar deposits contain barite only in their upper parts.

An often described peculiarity of Freiberg is the enrichment of the fluobaritic veins at their intersection with the older "kiesig-blendige" veins. Many of these ore shoots have been surprisingly rich. They are in several points very similar to the enrichments in the belt of cementation, but they occur even in the deepest levels of the mines (about 700 meters deep) and are the product of hypogene cementation as the result of younger ore-forming solutions acting on the older veins. The mineral content is very like that of the celebrated ores of Kongsberg, which are of similar mode of origin. In some parts of the district

[7] Beyschlag, Krusch, u. Vogt, "Die Lagerstätten der nutzbaren Mineralien und Gesteine," Bd. II., 2nd ed., p. 189.

rich mineral veins occur not at the intersections but as independent veins. The mineral content of these small but rich veins is very much like that of the intersections, although native arsenic, the leading mineral of primary cementation, is very rare in them and siderite and argentiferous tetrahedrite are more abundant than in the intersections. Primary cementation has often been at work in forming these veins, for they occur only where the older veins are very crowded, but probably they do not date from the latest fluobaritic time, but are of the same age as the "noble" quartz formation in the outer part of the district but telescoped into the inner part and enriched by primary cementation. Southwest of Brand such veins distinctly form a zone bordering the kiesig-blendige.

Another matter of controversy as to the general distribution in the carefully studied Freiberg district is the fact that in very old times (14th century) the outcrops of some lead-zinc veins are said to have been worked for tin. This resembles to some extent the deposits of Mount Bischoff, where the tin ores are also passing to sulphide ores in depth. But it is not necessary to assume the quite irregular zonal position—Sn, Pb, Zn—for these lodes. We know that the sphalerite of Freiberg, which has a large iron content, also contains a little tin and it is therefore probable that the tin ores at the outcrop were an enrichment in the belt of weathering.

The ore deposits of the Harz, though all are closely connected with large batholiths of granite, are quite free from tin ores. Only in one of the several districts, that of Neudorf, a little tungsten occurs and here we have also much fluor spar, which in the district of Clausthal, by far the greatest of the Harz, is entirely missing. Lossen [8] already in 1882 had shown a clearly defined "zonal distribution" of the Neudorf ores in connection with the adjoining Ramberg batholith. The ores of Clausthal consist of galena, sphalerite (increasing with depth), quartz, ankerite, and barite. They are no doubt high level ores. A strange type of veins are those of Andreasberg, small but very rich in silver with

[8] Lossen, *loc. cit.*

native silver, native arsenic, and even dyscrasite and other antimonides. They are similar to the ores of Kongsberg and to the Freiberg intersection ores. There must have been some enrichment, but there are no older sulphide deposits and the erosion in all the hilly country around has been very strong, so that the zone of weathering in the Harz is everywhere very small. The veins

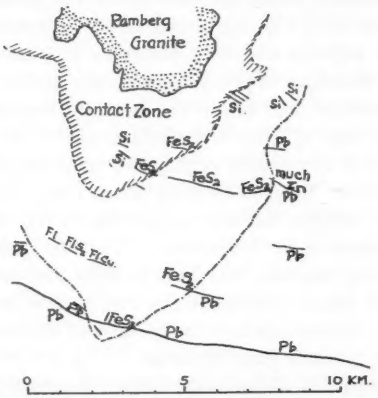

FIG. 3. Relation of vein filling to the Ramberg batholith at Neudorf in Harz. Dot and dash line is limit of quartz-pyrite-fluorite ores to lead ores, running conspicuously parallel to limit of contact zone.

of the Andreasberg are argentiferous only within a small block of rocks limited by great faults, and P. Krusch[9] therefore assumes that this block with its rich veins has been faulted down from an old belt of supergene enrichment which has long been destroyed in the country around. It is remarkable that the Clausthal veins in the direction towards Andreasberg are of increasing silver content, so that we may assume that galena veins, high in silver, were the primary ores that were enriched. The theory of Krusch is very plausible but difficult to prove. The ores faded away with increasing depth, the last small shoots being worked 800 meters below the surface. In the ores even at that depth were found

[9] Beyschlag, Krusch, u. Vogt, *loc. cit.*, p. 206.

very many vugs. We may call to mind here the theory of electric polarization brought forward by K. Hummel,[10] that a metallic deposit extending from the surface waters rich in oxygen to the deep underground waters poor in oxygen acts as a galvanic "element" with an anodic pole in depth and a kathodic pole near the surface. This must greatly strengthen weathering and oxidation, causing oxidation even below the groundwater level. The solutions of this strong oxidation at Andreasberg were held between the impermeable fault planes as in a tube. Secondary enrichment, therefore, was especially strong and concentrated.

The remarkable fact that in the Harz the ore deposits though located very near to granitic batholiths are of the medium-temperature type is accountable perhaps, by assuming that the Harz-granites are not the last granitic extracts of the deep seated reservoir of magma, but are comparable to the older non-stanniferous granites of the Erzgebirge. The "tin granites," *i.e.*, the last ore-bearing magmas, remained in depth and could only form medium-level deposits in the regions that lie now about 0 to 1,000 meters from the surface and at the time of mineralization were at a depth of 2,000 to 3,000 meters.

The scarcity of ore deposits in Silesia[11] is caused by a very deep erosion in Mesozoic times. The country is of decided hypobatholithic type. The large batholith of Lusatia has caused only a very insignificant copper vein at Ludwigsdorf, a trace of cobalt ore at Rengersdorf, and a few veinlets with quartz and wolframite at the Koschenberg. All the western part of the Riesengebirg granite massif is barren. In the eastern part we find poor deposits of arsenopyrite with traces of wolframite and scheelite and veinlets of quartz with galena and sphalerite near the large iron ore bodies of Schmiedeberg. It is only at the northeastern end of this batholith that we find deposits of some economic value: at Rothenzechau (arsenopyrite) and at Kupferberg (deep-level copper ores with fluorspar and albite). At Kupferberg can be seen

[10] K. Hummel, "Einiges über die Geologische Bedeutung der Erscheinungen spontaner Polarisation an elektrisch leitenden Gesteinen," *Centralbl. Mineralogie*, 1924, p. 66.

[11] Compare G. Berg, "Der Erzbergbau in Schlesien," *Metall u. Erz*, 1923, p. 401.

that the roof pendant is less steep than elsewhere, the contact metamorphic rocks appearing once more at the surface at a fault more than a mile distant from the granite. Farther on in this direction at Altenberg is a district with numerous dikes and necks of abyssal, nearly granitoid, quartz porphyry, and between these dikes and necks are some rich veins of chalcopyrite and arsenopyrite. The veins are gold-bearing; and the same is true of the contact-metamorphic deposits of Reichenstein at another small batholith farther east. These poor deposits are the only gold-bearing veins in Germany, and together with the gold-quartz veins of southern Bohemia, the only quartz-gold veins of Carboniferous age in Central Europe, except those of the Alps. The lean gold deposits of Carinthia are perhaps of Tertiary age, and the rich gold deposits of Hungary and Transylvania are truly of Tertiary age. We see that quartz-gold veins certainly are not to be set into a position of zonal distribution, either above or below the tin ores, but that they are a parallel type to the tin veins that are formed in the vicinity of magmas poor in tin and somewhat rich in gold. They range from pegmatitic quartz-feldspar veins to arsenopyritic and pyritic quartz veins, in places with transitions to lead-zinc veins. It is remarkable that the feldspar of pegmatitoid tin veins is usually orthoclase or microcline, that of the pegmatitoid quartz gold veins is usually albite. This fact shows clearly that the difference between quartz-gold veins and tin veins is rather the result of a difference in the chemical constitution of the magma than the result of their position in zonal distribution.

A deposit of small economic value but of great geologic interest is the tin and cobalt-bearing schist of Querbach and Giehren. This is the only clear example of a deposit in Central Europe formed by the Caledonian metallogenesis. It is located in a zone of schists intercalated in a gneissic granite of ancient Paleozoic age. The gneissic granite underlying this zone of schists is highly pegmatitic and rich in tourmaline. At the contact of granite and schist the latter is impregnated with tourmaline on both sides of small veinlets of quartz. A little farther from the granite there is a bed of garnetiferous mica-schist, and this is impregnated with microscopic tin ore where it is nearest to the

pegmatitic granite, and with cobaltite and cobalt-arsenopyrite where it extends to a greater distance from the pegmatitic part of the granite. It is a true example of the zonal distribution Co and Sn in the Caledonian metallogenesis.

The ore deposits of Przibram in Bohemia are like those of Freiberg and Clausthal, carrying like the latter some carbonates and barite. There are two sets of ores: the galena ores and the quartz-ores (Dürr-Erze) the one comparable to the kiesig-blendig ores, the other to the "noble" quartz ores of Freiberg. In former times the Bohemian geologists were of the opinion that the quartz ores had a lower primary position than the galena ores, but R. Kettner [12] showed that they are distinctly younger than the galena ores and commonly extend upward to the surface. We have seen that the quartz ores of Freiberg are more apomagmatic (of a higher zone) and farther away from the cryptobatholithic center of the district than the kiesig-blendig. The same is true of the two types of ore at Przibram, but the quartz ores are "telescoped" in the region of the galena ores.

The valuable lead-zinc lodes of Rhenania are far distant from any batholith. If we assume that every lode system of greater extension is genetically connected with intrusives, then the feeding batholith must be very deep and very extensive. We know only that the tuffs and trachytes of Tertiary volcanic action common in Rhenania enclose some abyssal rocks metamorphosed by the trachytic magma [13] and therefore older than these volcanic rocks.

H. Vogel [14] has shown that the lodes of Rhenania though trending in different directions are located in distinct zones of NE–SW extension. He thinks that these zones are formed by large fractures in the pre-Devonian basement and that in the overlying schist (Lower and Middle Devonian) the fractures died out in fissures of different directions. That may be true, but it is also

[12] R. Kettner, "Zur Stellung der Przibramer Dürrerze," *Bergb. u. Hütten.* p. 403, 1918.

[13] R. Brauns, "Über Laacher Trachyt und Sanidinit," *Sitz. Ber. Naturhist. Ver. Rheinl. u. Westfalen,* 1911, p. 1.

[14] H. Vogel, "Betrachtungen über den Aufbau des Rheinischen Schiefergebirges . . . sowie der darin auftretende Erzlagerstätten," *Verh. Naturhist. Verein Preuss. Rheinlande,* 1919.

possible that the zones are caused by ridges on the underlying batholiths. Surely the Rhenania cryptobatholithic deposits are remarkably apomagmatic. In the upper parts they carry much galena; in depth sphalerite and chalcopyrite are increasing. An outer zone of quartz-silver ores is not distinguishable, but near Bensberg in the district of the lead veins there are small veinlets of such a typical high-level mineral as cinnabar. Besides quartz, siderite is an important mineral in the veins, but we learn in examining the formations of Siegerland that all the country is mineralized by an early Devonian mineralization of siderite. Therefore, it is possible that a great part of the carbonate has been regenerated from earlier sideritic veinlets.

A proof that the Rhenanian lead ores were not formed in great depths is also given by the distribution of the metal in the Eifel Mountains. Here the galena occurs at several hundred localities forming veinlets in any part of the slate and limestone but very rarely concentrated to a workable deposit. The best deposits are of metasomatic origin at the contact of slate and limestone and impregnations of Triassic sandstones near Mechernich which are poor but easily workable and easy for mechanical concentration. The dependency of ore shoots on the adjoining rock is everywhere very marked in Rhenania, just as it is in high-level deposits.

An enigmatic deposit far distant from any batholithic intrusive is the large belt of metasomatic zinc-lead ores in Upper Silesia at the contact of Middle Triassic dolomitic limestone with an underlying bed of clayey slate. The distance of these ores from the surface at the time of mineralization was surely only a few hundred meters; but the distance from the hypothetical underlying batholith is at least two thousand meters, for there is not any trace of a batholith or batholithic contact metamorphism even in the deepest coal mines of the adjoining and underlying Carboniferous strata.

The most interesting deposits of western Germany are the sideritic lodes of the Siegerland, which are described in a very carefully prepared monograph by W. Bornhardt.[15] These iron

[15] W. Bornhardt, "Über die Gangverhältnisse des Siegerlandes und seiner Umgebung," *Archiv. für Lagerstättenforschung*, Heft 2 u. 8.

ores have been proved to be of Middle Devonian age, for they form lodes in Lower Devonian slates and graywacke and were metamorphosed to magnetite by dikes of diabase of Upper Devonian or early Lower Carboniferous age. The mineralization probably is highly apomagmatic and very dependent on the adjoining rocks in a mechanical sense. The lodes are rich in medium-grained and poor in slaty and coarse-grained sediments. The vein-forming solutions must have been nearly completely carbonatic. It is not sure that the iron content is really of pure magmatic origin, for it is possible that the ores were formed by a deep underground circulation in the sense of Van Hise, the carbonatic content of the solutions being separated by differentiation through crystallization into carbonates of iron and manganese, which were deposited in the fissures, and carbonates of calcium and magnesium, which were borne away to the surface. The deepest mines of the Siegerland attain a depth of 950 meters, but there is no difference in the character and manganese content of the siderite filling. The form and distribution of the ore shoots are very interesting. They are bound to tectonic fractures but go down along these fault planes in inclined direction. The ore shoots very clearly were the passage ways of the ascending solutions. They are, so to speak, petrified thermal springs.[16] With the siderite is combined a little sulphide ore of primary deposition, mostly pyrite, sometimes pyrrhotite, chalcopyrite, and cobalt sulphides. Metasomatic replacement of the rock adjoining the normal sideritic ore shoots was very weak.

Large parts of the siderite veins were transformed during a later period of mineralization to quartziferous sulphide veins by processes of internal lode metasomatism (innere Gangmetasomatose).[17] These younger ores are distinctly more perimagmatic, and belong to a deeper level of zonal distribution than the sideritic filling of the veins. The process is not a telescoping but a *re-*

[16] H. Quiring, "Das Gesetz des Einschiebens und der Vertaubung der Spateisenstein-und Eisenglanzgänge des Siegerlandes," *Archiv. für Lagerstättenforschung*, Heft 33.

[17] P. Krusch, "Die mikroskopische Untersuchung der Gangausfüllungen des Siegerlandes," *Archiv. f. Lagerstättenforschung*, Heft 8.

juvenation of ore deposition. These later ores are very closely connected with the ores of the Rhenania lead-zinc district, which immediately adjoins the Siegerland. Some veins in the borders of Siegerland are nearly entirely filled with pure quartz-sulphide ore and contain only traces of sideritic filling. These are not distinguishable from the Rhenania ores. In general the later sulphides of Siegerland are a little more perimagmatic than the Rhenanian, copper playing a greater part in them. In the southern part of Siegerland at Wipperfuhrt is a single lode of quartzose copper ore containing only traces of the earlier siderite filling. Some other sulphide fillings go farther on in apomagmatic zones. Tetrahedrite and at Littfeld even a little mercury is known, but many of the ore shoots that are rich in copper with chalcocite, tetrahedrite, and others, were formed by supergene enrichment and are restricted to the surface.

The combination of older sideritic ores and younger quartzose sulphide ores is very irregular. Quartzose fillings often cut off the siderite in depth, but we know a great many places where the contrary is true, and the mines went through a quartzose part and found a good siderite shoot in greater depth.

In accord with the more perimagmatic nature of the later ores the metasomatic action on the adjoining rocks was far more intense adjoining the quartzose than that adjoining the sideritic parts of the veins. Bleaching and kaolinization are very strong near the sulphide shoots. A unique type of metasomatism is the forming of red spar, recently described by Quiring.[18] It is not always connected with the sulphide shoots but it is another result of internal lode metasomatism. The siderite is crowded with small blebs of specularite and therefore turns to a red color. Ordinarily the shoots of red spar are rich in quartz, evidently introduced into the formerly normal sideritic ore, and in the case of intense replacement, the shoot consists entirely of quartz and specularite. The red spar shoots are very irregular, ordinarily of vertical extension. They are not bound to the zone of weather-

[18] H. Quiring, "Das Gesetz des Einschiebens und der Vertaubung der Spateisenstein und Eisenglanzgänge des Siegerlandes," *Archiv. für Lagerstättenforschung*, Heft 33.

ing, the normal oxidation of the siderite veins producing limonite and in part pyrolusite in botryoidal forms. The specularite must have been produced by later solutions than those which produced the siderite. Probably the process belongs to the same metallogenesis as that which produced the quartzose sulphide shoots, but the composition of the solutions must have been different, for the sulphides can only exist in a reducing environment and the altering of siderite to specularite is an oxidizing process. The specularite-quartz veins are situated at both ends of the long extended district of workable siderite lodes where the iron content diminishes and only strongly sulphide lodes are workable as lead-zinc ores. Sideritic veins are very widespread in Central Europe but are generally of great geological age. This and the tendency of siderite to undergo metasomatic processes has brought about that the sideritic veins generally contain quartzose sulphide ores of younger formation. The veins of Lobenstein in southern Thuringia are small but nearly pure siderite veins, with but a small content of copper and nickel minerals but often quartzose without sulphides. Pure siderite veins also occur in the Alps near Salzburg, but the greatest deposits of vein-forming iron carbonate in the Alps are the ankerite veins of Mitterberg; they are workable only for their high content of copper ores, consisting of chalcopyrite and in part tetrahedrite with quartz, these sulphides being distinctly younger than the siderite and ankerite. At Kitzbühel, not far from Mitterberg, the quartz-sulphide ores prevail over the carbonates and the sulphides are not only copper but also lead-zinc ores, thus showing that Kitzbühel is a little farther from the center of the rejuvenation than Mitterberg. There are a great many small deposits of sulphidic ores scattered through the eastern Alps. The distribution of these deposits is very irregular and a zonal arrangement is not yet distinguishable. It is remarkable that tin ores are unknown in the Alps; only some localities of molybdenic lead ores are known. But gold contents in pyritic, arsenopyritic, and even in lead-zinc ores are often found in that part of the eastern Alps called the Tauern, which probably are to be considered as the center, or one of the different centers, of this metallogenesis, which is surely not of Carboniferous, but of post-Triassic, probably Tertiary age.

The deposits of the "Hungarian Erzgebirge" (now belonging to the Czechoslovakian Republic) are astonishingly similar to those of the Siegerland. A primary sideritic vein filling with a few primary sulphide ores was rejuvenated by internal lode metasomatism with quartzose sulphide ores. A zonal distribution of these ores is readily distinguishable. Nevertheless tin ores and fluorite are unknown, but in the western part, where a large batholith of granite comes to the surface,[19] copper ores are abundant, at Iglo and Rostoken even with some prisms of tourmaline as a mineralogical rarity. South of these deposits at Dobschau cobalt-nickel ores occur with a little more tourmaline piercing the siderite in the form of fine needles. A zone of zinc and lead is not distinctly developed, but neither galena nor sphalerite are entirely absent in the eastern mines. The tendency is more to change from chalcopyritic to tetrahedritic copper ores. Most remarkable is the presence of mercury ores at Kotterbach, one of the eastern deposits of this district.

The age of the sideritic as well as the quartz-sulphide ores of this district is unknown. The siderite forms fissure veins in a great fault that limits the Devonian against Carboniferous strata. The siderite therefore is of post-Carboniferous age and later than that of the Siegerland. South of Dobschau we find at Kremnitz and Schemnitz quartz-sulphide veins with rhodochrosite and high gold contents associated with volcanic rocks of Tertiary age. The age of all of the sulphide ores of the Hungarian Erzgebirge is probably Tertiary. As in the Siegerland we have late Caledonian siderite with Carboniferous rejuvenation, so in Hungary we have late Carboniferous siderites with Tertiary rejuvenation. The siderite of the Siegerland is remote from the Caledonian center of metallogenesis in Scandinavia, and the siderite of Hungary is far distant from the center of Carboniferous metallogenesis in Germany.

Farther east we enter into a district of purely Tertiary metallogenesis which extends all over Transylvania and some parts of northeastern Serbia. The formation of ore deposits is there no

[19] The granite of the Tatra, which is much nearer to the copper deposits of Iglo, is not really a batholith but its "mise en place" is of tectonic origin.

longer of plutonic but of volcanic type. This distinction, first brought forward by P. Niggli [20] and H. Schneiderhöhn [21] and the author of this paper,[22] is not yet sufficiently taken into account in America. It is a distinction based on whether the magma, the exhalations of which brought forth the ore-bearing solutions, has consolidated as a holocrystalline rock at great depth or whether it advanced nearer to the surface before the solutions and exhalations were segregated. In volcanic rocks, owing to the smaller pressure, the gases and solutions will escape from the magma much more quickly, and they will not proceed so far through the adjoining rocks before cooling, but will fill with their mineral content especially the cracks and fissures of the volcanic rock itself or of the volcanic neck that fills the eruption channel to the Earth's surface. As the path from the molten magma to the cold surface is short, cooling is rapid and extends quickly back to the ore-bearing magma. Telescoping, therefore, is no longer an exception but is the rule governing the deposition of ores. Silica is deposited partly as chalcedony or chert, the intense resurgence of water-vapors tends to form zeolites, and the metasomatism of adjoining rock does not proceed far from the ore veins but is very thorough.

No doubt there are transitions between volcanic and plutonic types of ore deposits. No doubt a volcanic eruption probably depends on the existence of a batholithic magma reservoir in greater depth. But it is a difference whether the liquid segregations of the magma force their way with slowly diminishing pressure up through a long distance in fissures through the rocks or whether they are brought to the surface by hot and explosive volcanic lavas.

The typical volcanic ore deposits are the gold and silver deposits that are associated with volcanic necks; they were at first called by Beyschlag, Krusch, and Vogt the "younger gold-silver veins."

[20] P. Niggli, "Lehrbuch der Mineralogie," Berlin, 1920; *Abhandl. f. prakt. Geol.* Heft. 1. Halle, 1925.

[21] H. Schneiderhöhn, "Bildungsgesetze eruptiver Erzlagerstätten u. s. w.," *Metall u. Erz,* Heft 12, 1925.

[22] G. Berg, "Probleme der Lagerstättenlehre," *Geologische Rundschau,* Bd. 13, Heft 4.

We now know also volcanic deposits of lead-zinc ores (the kuromono masses of Japan). We know volcanic copper ores (enargite is a mineral especially characteristic of them). From Bolivia have recently been described tin ores that contain chalcedony and ruby silver, a typical telescoping of the whole order from tin to antimony.

The ores of Transylvania, as is generally known, are of the younger gold-silver type, and the ores of Bor in Serbia are enargitic ores in volcanic rock of Tertiary age. In both districts the rocks are andesitic and highly propylitized. Between these two districts is a region of a somewhat plutonic character, the Banat. Rocks of granitic, porphyritic, and even felsitic type have produced in limestones magnetite deposits of the contact type. At Rezbania, which lies between the two centers of Tertiary ore deposits in Transylvania, the Offenbanya and the Ruda-Verespatak centers, there are ores of bismuth, copper, and lead, forming younger impregnations of contact metamorphic garnet rocks. This is another resemblance to plutonic ore formation, and it is remarkable that it occurs in the middle part and the lowest part of the long line of Tertiary volcanics extending from Transylvania to northern Serbia. In general since Tertiary time the erosion has not yet proceeded deep enough to expose the plutonic ore deposits that probably accompany on both sides of the volcanic line the batholithic reservoir of the Tertiary lava.

The deepest parts in the Banat are near to the acrobatholithic type of Emmons; the others to the north and south are not cryptobatholithic, that is to say, deep or medium level and apomagmatic like the common lead-zinc ores remote from batholiths, but they are volcanic, that is to say, high-level and perimagmatic.

CONCLUSIONS.

The distribution of ore deposits in Central Europe is far less conspicuously zonal around batholiths than it is usually found to be in America and in Cornwall. Therefore, the zonal theory was not brought forward in former times by German or Austrian geologists. Nevertheless, zonal distribution can be discerned at several localities, but the telescoping of the inner and outer zones

in the same district is frequent and darkens a clear view of the distribution. Cryptobatholithic deposits in the sense of W. H. Emmons are very widespread. In many districts, especially in the Siegerland, in the Hungarian Erzgebirge, and at Mitterberg we find *rejuvenation, i.e.,* renewed mineralization of older apomagmatic lodes of siderite by the metasomatic introduction of quartz-sulphide ores, which are more perimagmatic than the siderite and belong to a younger metallogenesis. The author believes that it is not possible to introduce the pyritic, arsenopyritic, quartz-gold veins at any point into the customary order of deposits: Sn, Bi, Cu, Zn-Pb, Ag-Sb, Hg. The gold-quartz veins with their transitions to pegmatite veins (ordinarily albite pegmatite) are of coördinate formation with the tin deposits, which also have their transitions to pegmatites (ordinarily orthoclase pegmatites). The difference between the pegmatite tin and the gold veins is not one of zonal distribution but is one that is dependent on the constitution of the parent magma. Both unite in the upper and outer zones to form lead-zinc veins. Nor are the rich gold-silver veins to be intercalated into the customary order just given. That order is the order of the zonal distribution around deep-seated *plutonic* batholiths, and is developed during slowly diminishing temperature and pressure. But the rich gold-silver deposits, the enargitic copper deposits, and many others called by Niggli and the author the *volcanic* type were derived from magma that filled volcanic necks. They have been formed close to the magma, *i.e.,* as perimagmatic deposits, but nevertheless have been formed near the Earth's surface.

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PRELIMINARY REPORT ON THE ORIGIN OF CALIFORNIA PETROLEUM.[1]

JUN-ICHI R. TAKAHASHI.

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INTRODUCTION.

It is an interesting fact that the Monterey formation which is the reservoir of a considerable part of the petroleum in California, and is commonly considered the probable source of the oil, resembles closely the oil measures of Japan, not only in general geological features, age, and fossil content, but in composition, lithological features of the associated rocks, and in the mode of occurrence of the petroleum. Such similarity has stimulated this investigation, to examine more in detail the diatom theory of the origin of petroleum in California. The theory is sometimes exaggerated when cited, though the original authors are cautious enough not only to avoid positive affirmation of the theory but also to recognize that some other fossil organisms have contributed to the origin of petroleum. The chief purpose of this paper is to make clear whether the white, light diatomaceous earth predominating in the upper zones of the Monterey

[1] The synopsis of this paper was read before the Annual Meeting of Geological Society of America (Cordilleran Section), May 5, 1924.

formation can be recognized as a reliable guide in prospecting. An attempt is therefore made to present a complete report of a chemical and microscopical investigation of the Monterey shales and other diatomaceous deposits of California, and a discussion of the petroleum-forming process in the Monterey formation.

The investigation had been carried out by the writer at the Tohoku Imperial University of Japan, until he came to the University of California, where, by the courtesy of the faculty he has been able to continue his investigation of numerous collections of the oil formation of California.

Acknowledgment is due to Prof. G. D. Louderback, of the University of California, who placed material from his own collection at the writer's disposal, read the paper in manuscript, and gave valuable advice. I am also indebted to Prof. S. Kozu of the Tohoku Imperial University, and Dr. I. Omura of the Nippon Petroleum Company, whose courtesies and kindness added materially to the value of this report; to Messrs. T. Yagi and T. Moriya who performed elaborate chemical analyses; to Prof. J. B. Macelwane of the University of California; and to Mr. J. M. Atwell, general manager of the Producing Department of the Standard Oil Company of California and his staff. I am particularly indebted to Mr. Wm. S. W. Kew of the Standard Oil Co. of California for his kindness in preparing the manuscript for publication.

GEOLOGIC THEORIES OF THE ORIGIN OF PETROLEUM IN CALIFORNIA.

As early as 1893, "the bituminous shale" (Monterey shale) was considered by Lawson [2] the source of the asphaltum deposits which are found associated with this rock. Simple tests revealed that the Monterey shale, however white it may appear, contains bituminous substances; and he was led to the conclusion that the ultimate source of the carbonaceous substance in the shale was undoubtedly the bodies of minute organisms, the larger parts of whose shells, aside from those detected under the microscope,

[2] Lawson, A. C., Univ. Calif. Bull. Dept. Geol. Sci., Vol. I., No. I., pp. 1–59.

were removed by leaching. Many geologists working in the California oil fields, however, seem to have paid no more attention to Lawson's suggestion, but advocated a theory of diatom origin for the California oil.

Arnold [3] and his associates have stated that they were strongly of the belief that the oil in the Santa Maria District is indigenous to the Monterey shale and that certain ingredients of the shale,—namely, those organic remains which they had detected, are undoubtedly responsible for the origin of the oil. They further maintained that the petroleum was derived largely from the minute organisms, especially diatoms, that are so abundant in the Monterey shale.

According to Arnold, the oil in the Summerland fields [4] originated by slow distillation from diatoms and other organisms in the thick Monterey shale. The same hypothesis seems to apply to other coastal oil fields, such as Santa Clara, Puente Hills, and Los Angeles.[5]

The diatom theory has also been advocated for the oil deposits of the San Joaquin Valley. In the Kern River District, strata resembling the Monterey are regarded as the source of oil.[6] In the McKittrick field,[7] the oil is considered as having originated in the diatomaceous shale of the Monterey (lower middle Miocene) and Santa Margarita (upper middle Miocene) formations and to have migrated into the porous layers. The oil in the Sunset-Midway fields is considered by Pack [8] to have originated in the diatomaceous shale formation (represented partly by the Maricopa and partly by Vaqueros formations, middle and lower Miocene re-

[3] Arnold, R., and Anderson, R., U. S. G. S. Bull. No. 317; Arnold, R., and Anderson, R., U. S. G. S. Bull. No. 322; Arnold, R., Two Decades of Petroleum Geology, 1903–22, *Bull. Amer. Assoc. Petrol. Geol.*, vol. VII., No. 6, pp. 603–624, 1923.

[4] Arnold, R., U. S. G. S., Bull. No. 321, p. 21, 1907.

[5] Eldridge, G. H., and Arnold, R., U. S. G. S. Bull. No. 309, 1907.

[6] Arnold, R., and Garfias, W. R., *Amer. Inst. Min. Eng.*, Bull. No. 87, pp. 383–470, 1914.

[7] Arnold, R., and Johnson, R., U. S. G. S., Bull. 406, 1910.

[8] Pack, R. W., U. S. G. S., Prof. Paper 116, Part 1, 1919. The Maricopa shale is in reality cherty or calcereous for the greater part.

spectively) from organic substances contained in diatoms and foraminifera.

In the Lost Hills region the Santa Margarita formation (upper middle Miocene) is believed to be the source rock of the oil. The oil from the Chico (upper Cretaceous) and the Tejon (upper Eocene) formations in the Coalinga oil fields [9] is considered to have originated in the formations themselves. That is, the paraffin oil therefrom originated in the foraminiferal shale in the Chico formation and the asphaltic oil, from the foraminiferal and diatomaceous shale of the Tejon formation.

To summarize their theory briefly,—they first present strong field evidence to show that the California oil is indigenous to certain formations containing organic remains, especially to the Monterey shale. There seems to be no reasonable ground to doubt that shale of organic origin such as the Monterey shale is the parent source of the oil. This is accepted by many of the geologists working in the California fields, and the present writer does not hesitate to share their opinion.

This led to the inevitable conclusion [10] that certain ingredients of the Monterey shale gave rise to the oil. After examining the organic composition of the strata making up the formation the writers mentioned above enumerated a number of animal and plant bodies that may possibly have contributed material for the production of oil. Among these were fossil fish, sponges, molluscs, crustaceans and kelp. But they failed to look upon these kinds of fossils as the chief material from which the oil was derived, believing that these organisms had not been deposited in sufficient quantity. This belief was based on the scarcity of the fossils found and on the theory of the improbability of their being buried in the deposits.

Their conclusion that diatoms were the main source of the oil, with foraminifera and radiolaria to a much less extent, rests upon the fact that although these organisms are possible sources of petroleum chemically and biologically, diatoms are much more plentiful in the Monterey shale than in other formations, the

[9] Arnold, R., and Anderson, R., U. S. G. S., Bull. No. 398, 1910.
[10] Arnold, R., and Anderson, R., U. S. G. S. Bull. No. 322, pp. 109–113.

former being in places made up entirely of diatom tests. Their conclusion was strengthened by their observation that the oil deposits are usually associated with diatomaceous shale, the most productive oil fields being found in direct association with this type of shale, whereas the strata are barren of oil where the adjacent Monterey shale is devoid of diatoms.

But it must be recognized that such an apparent association of oil and diatoms is only vague. Pure diatomaceous shale usually predominates in the upper zone of the Monterey formation where the strata are soft and unconsolidated, whereas the oil of economic importance usually occurs in the lower zones of the formation, sometimes migrating therefrom to the upper zones. How, then, can the abundance of diatoms in the upper zones account for the prolific oil deposits in the lower zones? Moreover, the diatomaceous shale varies greatly in its thickness and in its content of diatoms in the different oil fields, irrespective of the amount of petroleum contained. It is stated that some of the most productive oil fields are found at those places where the formations are made up of pure diatom earth. Roughly speaking, this is also true in some of the productive oil fields of Japan.[11] For example, the oil deposits of Niitsu and Kurokawa, apparently are found in thick beds of highly diatomaceous soft shale. Careful study,[12] however, reveals that such beds seldom contain diatoms. The designation diatomaceous shale includes several kinds of shale, grading from almost pure diatomaceous earth to practically non-diatomaceous shale. Tuffaceous shale in the Nishiyama oil fields, for example, was erroneously described as diatom earth.[13] On the other hand, formations devoid of diatoms have yielded petroleum of similar character and volume to that obtained from diatomaceous formations.

[11] Takahashi, J., "Marine Kerogen Shales from the Oil Fields of Japan, etc.," Tohoku Imp. Univ. Sci. Rept., ser. III., vol. I., No. 2, 1922.

[12] Takahashi, J., "Brackish Water Shale in the Okohdzu Cut and its Significance to the Petroleum Deposit," *ibid.*, vol. II., No. 1–2, 1924; "On So-called Contact Phenomena of the Tertiary Oil Measure Shales Caused by Rhyolite Rock, etc.," *ibid.*, vol. II., No. 1–2, 1924.

[13] Otsuka, S., Imp. Geol. Surv. Japan, Expl. Text. Geol. and Topogr. Map of Petroleum Field, No. 3, Nishiyama (Japanese).

Similarily in California, as for instance, in the San Joaquin Valley, most of the Maricopa shale is not diatomaceous, but siliceous or marly. The scarcity of pure diatom earth in the Coalinga oil field has already been mentioned. But it goes too far to say that oil and diatoms are so intimately associated that the diatoms are a reliable guide in prospecting either in Japan or California.

The white diatomaceous shale of the Monterey formation is often devoid of organic substance, except for bitumen impregnating it from without, though the hard shales of the lower zones are usually found to contain kerogen. How was the organic matter of the diatom altered to petroleum? If it were due to natural distillation, how was the fixed carbon, which must have discolored the shale, bleached? Was not the shiale, in part at least, an accumulation of the discarded shells of diatoms? Were the diatoms alone deposited? Can the fossils retained in the shale be considered to represent exactly all of the organisms which might have thrived in the areas at the time of the deposition of the Monterey shale? Is the closely associated occurrence of important oil deposits with diatomaceous shale to be simply attributed to their genetic relation? Or can it be explained in variations in its accumulation or in the difference in sedimentation? All these questions must be answered before the diatom theory of the origin of petroleum can be perfectly established.

The abundance of diatom remains in the Monterey shale does not mean necessarily that the sea in which the shale was deposited swarmed with diatoms and contained no other organisms, nor that diatoms predominated over other organisms that might have lived in the same sea and contributed to the organic components of the shale without leaving fossil remains. Therefore, the relative proportion or kinds of fossils found in the shale, neither represents the true proportion of the organisms (or their decomposition products) originally contained in the shale, nor the entire organic components. Consequently the chemical character of oils can not be interpreted on the basis of the kind and proportion of the fossils contained in the source rock, and oil may be produced from formations deficient in fossils.

On the other hand, it is questionable whether the remains of organisms found in shale contained any appreciable amount of organic substances at the time of burial; they may have been merely discarded skeletons. Thus, no reliable evidence has been presented to prove that the diatomaceous shale of California oil fields is not a mere accumulation of discarded tests of diatoms.

The diatom theory advanced by Arnold and his associates is based upon the belief that the fossils now found in the shale represent the original character and relative proportions of the organisms that at any time contributed to the component of the shale. In this connection, the latest view of Pack seems somewhat different from the above, for he states: [14]

> ". . . and it is from the decomposition and alteration of these organisms (diatom and foraminifera) that the petroleum now found in the Sunset-Midway field results. In parts of the region the organic material contained originally in the fine-grained beds appears to be not so much the remains of diatoms as of larger terrestrial vegetation, and it is probable that part of the petroleum has been formed by the alteration of this coarser vegetable material. But in any case it seems clear that the ultimate source of the petroleum is the organic material originally contained in these beds."

Thus, Arnold, Anderson and Pack appear inconsistent in detail. They are generally cautious enough to avoid any positive affirmation of the theory, but recognize foraminifera and the "coarser" vegetable materials as the source of some of the oil in California.

The interesting suggestion of Branner [15] that the diatomaceous shales of the Monterey series in the San Joaquin Valley were produced by diatoms being floated by a hypothetical ocean current into a *cul de sac* at the southern end of the present valley, seems to afford a possible interpretation for the origin of the Monterey shale and the oil therefrom. It, is, however, speculative, and lacks reliable data, as suggested by Professor Louderback.[16]

[14] *Op. cit.*, pp. 70–71 (origin of the petroleum).

[15] Branner, J. C., *Bull. Geol. Soc. Amer.*, vol. 24, pp. 94, 1913.

[16] Louderback, G. D., Univ. Calif. Pub., Bull. Dept. Geol. Sci., vol. 7, No. 10, pp. 177–241, 1913.

To arrive at the origin of oil, instead of attributing it directly to one or a few of the fossils, it is essential to determine the facies of deposition.

THEORIES BASED UPON CHEMICAL INVESTIGATIONS.

The nitrogen and sulphur compounds contained in the Californian oil has been specially discussed by Peckham,[17] who believes that the presence of nitrogen compounds in the oil is evidence of its origin from animal substances. A similar opinion is held by Clark.[18] Mabery and his associates[19] report that they prepared a long series of organic nitrogen bases from the Californian oil and obtained a derivative of pyridine. Rogers[20] also presents an important discussion of the character and chemical composition of the Californian oil. According to him, the Midway Sunset oil consists of naphthene, turpentine, aromatic, and hydrogen-poor hydrocarbons. Palmer[21] found phosphorus in the California heavy oil containing nitrogen bases. He thinks that this proves the animal origin of the oil.

In reply to some of these opinions of chemists, Arnold[22] states that it is "unnecessary to consider that this petroleum originated entirely from either animal or vegetable matter," and he refers to foraminifera as the origin of the nitrogen compounds. The chemical investigation of petroleum shows that there are oils with similar character and composition to that of California yielded by formations containing but few diatoms. Foraminifera are sometimes considered as the origin of oil in certain oil fields for the same reason that diatoms are so regarded in the Californian oil fields. Even in such cases, the oil is not reported to be richer in nitrogen content than the Californian oil. Thus, the chemical

[17] Peckham, S. F., "Notes on the Origin of Bitumen," *Am. Philos. Soc. Proc.*, vol. X., p. 445, 1868.

[18] Clark, F. W., Data of Geochemistry, U. S. G. S., Bull. 695.

[19] Mabery, C. F., and Hudson, E. J., *Jour. Soc. Chem. Ind.*, vol. 19. p. 504, 1900; Mabery, C F., and Wessen, L. G., *Jour. Soc. Chem. Ind.*, vol. 22, p. 1014, 1920.

[20] Rogers, G. S., U. S. G. S., Prof. Paper, 117, 1919.

[21] Palmer, C., Econ. Geol., vol. 17, No. 2, pp. 100–104.

[22] See last reference under note 3.

character of petroleum cannot be fully interpreted by the nature and relative proportions of the fossils contained in source beds.

Experiments show that the nature of oil may differ greatly under different conditions of distillation. Paraffin can be obtained from "asphaltic base" oil by suitable treatment, as is well known of the Baku oil. The writer also obtained white wax as well as a large proportion of gasoline from the heavy asphaltic base oils from the Niitsu and Akita oil fields of Japan.[23] In the last named oil field, paraffins were found choking the pipe of an exhausted oil well. Thus, the nature of oil largely depends on the conditions of natural distillation under which the oil is produced, not only the conditions of heat, pressure and time, but also the physical and chemical features of the natural distilling apparatus, the shale beds.

Petroleum is technologically said to be either of paraffin base or of asphaltic base. The base to which it is referred is often considered to be dependent on the composition of the original materials. This conclusion, however, does not always seem to be justified.

There seems to be no fundamental method for distinguishing crude petroleum and the distillates of oil shale or lignite, these being largely hydrocarbons, either saturated or unsaturated, which can be converted from the one to the other by proper treatment. However, they can be distinguished from each other by diazobenzol reaction, their odor, specific gravity, by measuring the iodine value, by detecting creosote, or by use of the polariscope. Such methods are sometimes effective, and the detection of the nitrogen and phosphorus compounds in the oil may give valuable information.

It must be borne in mind that all the organic substances that become buried in geological formations are invariably converted to, and preserved in, approximately similar substances. These substances may be called bituminous, if not carbonaceous. It seems that in the course of geological processes that may be

[23] Takahashi, J., "On the Effect of Mineral Substances on the Thermal Decomposition of Bitumens," Tohoku Imp. Univ. Sci. Rept., ser. III., vol. II., No. 1–2, 1924.

termed petroleum forming processes, all the organic substances are fated to be converted into either bituminous or carbonaceous material.

EXAMINATION OF DIATOMACEOUS SEDIMENTS CONTAINING ORGANIC SUBSTANCES, RECENT AND GEOLOGIC.

Kraemer and Spilker,[24] found some waxy substance contained in fossil diatom beds, and expressed the diatom theory of the origin of petroleum a few years in advance of the Californian geologists. The same theory was suggested by Stahl.[25]

Kraemer and Spilker obtained about one ounce of wax-like product by extracting one and a half pounds of the dry peat moss from Franzenbad with toluol and driving off the sulphur (about 10 per cent.). They gave the name "diatom wax" to the product, from which they separated a substance exhibiting the same chemical behavior as "lekene" which, according to Beilstein, characterizes ozokerite. The comparative investigation of the diatom wax and ozokerite led them to the conclusion that ozokerite is derived from diatom oil hydrolyzed by the ammonium carbonate and water formed by the decaying organisms, carbon monoxide and dioxide being excluded. They are of the belief that ozokerite and diatom wax, under the influence of moderate temperature and pressure, finally result in petroleum, which in the presence of sulphur is liable to become heavy oil. It was concluded that about 100,000 tons of this wax are contained in a stratum of diatomaceous lake mud averaging 23 feet in thickness, at Sudwigschof in Uckermark. Holde,[26] however, obtained some 77 per cent. of fatty- or colophony-like bodies from similar peaty beds and some lake deposits.

It must be noted that these diatomaceous deposits are rich in nitrogen compounds (attaining 3 per cent., and often used as fertilizer). They also contain a number of micro-organisms and the debris of higher plants. According to Potonie,[27] who ex-

[24] Kraemer, G., and Spilker, A., *Ber. Deut. Chem. Gesel.*, vol 32, s. 2940,

[25] Stahl, A. F., *Chem. Ztg.* vol. 23, s. 144, 1899; vol. 30, s. 18, 1906.

[26] Holde, D., "Mitteilungen," vol. 27 s. 1, 1909.

[27] Potonie, H., *Jahr. Kgl. preuss. Geol. Landes.*, No. 2, 1904; *Zeitschr. Prakt. Geol.*, 13, 1905; *Natur Wochensch.*, vol. 20, 1905, etc.

amined the very materials from which Kraemer and his associates obtained the "diatom wax," those diatomaceous deposits are not in reality diatom earth, but are mixtures of animal and vegetable remains and excretions, a sort of sapropel, which he considers to be the origin of most petroleum.

The writer also obtained waxy substances resembling leucopetrite by extracting various diatomaceous deposits of Japan. The waxy substances from the diatom earth of Tochibori (Lower Pliocene), the turf from Fukui (Pleistocene) and the lagoon mud of Kahoku (recent) vary greatly in their composition and solubility, irrespective of their diatom contents.[28]

The diatom earth from Tochibori consists of diatom tests, stained greyish by a carbonaceous substance that seems to be of vegetable origin. The upper part of the beds of the diatom earth is often weathered, being bleached white or of a light reddish tint owing to ferruginous pigment. Peculiar concretions, resembling green soap in appearance, in touch and in hardness, are found imbedded in the diatom beds. These concretions contain some sulphuric acid and ferrous sulphate, associated with globules of iron sulphide, which are entirely or partially decomposed to iron oxide. These facts suggest the origin of the concretions and how the diatom earth was bleached white, because the concretions are surrounded by a layer of the bleached diatom earth containing them. They were probably produced by the decomposition of pyrite which had been formed by the organic substances of the beds.

The diatoms of which the deposit consists are partly discform (or float bladder type) and partly of the "sessile" type. This suggests that there were other forms of life being deposited with the diatoms. Though there are no determinable remains of organisms preserved in the beds except those of diatoms, the writer hesitates to regard the organic material obtained by extracting the diatom earth as largely derived from the protoplasm of the diatoms. As already mentioned, similar organic substance may be obtained by extracting turf, peat, and muds from various water areas, irrespective of their diatom contents. The micro-

[28] See reference, note 11.

chemical tests of these sediments show that the organic substances are homogenously mixed with the inorganic colloidal substances. Moreover, in the Tochibori diatom earth, as in many other places, there are also fine carbonaceous substances which seem to be macerated debris of vegetable origin. Thus, it is clear that other organisms, mingled with diatoms, were also buried in the deposit.

In this relation, the recent investigation of the writer and his associates concerning the mud being deposited in the bottom of the Shiogama Bay,[29] has shown an interesting result, and will be briefly summarized below:

The Bottom Mud of the Shiogama Bay.—The bay is a shallow inlet in the Matsushima Bay, and is separated from the Pacific Ocean by many small islands. The mud was collected at three foot depth intervals from near the center of the bay where the depth of water does not exceed 5 meters. The shallow areas are usually covered by water plants, particularly by *Zostera marina,* thus affording a favorable environment for plancton and necton.

Besides containing colloidal substances, pyrodastic materials,—glauconite and iron pyrite, the mud is highly diatomaceous, so that under the microscope it resembles a true diatom earth. The diatoms of sessile type (colonial type) occur in far larger amount than those of discoidal type. The diatom of the former type probably lived attached to some water plants. The Shiogama Bay in the shallow areas becomes covered by *Zostera* in summer, but the remains of the plant are found as sparingly in the mud from a depth of 15 feet as in that of the bottom surface. Thus, no sign of the decrease of the diatom with increasing depth is observed.

In this connection, it is interesting to recall the observation of C. A. Davis and Chase Palmer [30] that peat of the Dismal Swamp contains diatom skeletons in perfect preservation. Planctonic diatoms are also found abundantly in the fine, sticky black mud occurring in the great depths of the Black Sea.[31] Besides iron

[29] See reference, note 12.

[30] U. S. G. S. Bull. 695.

[31] Andrussov, N., La Mer Noire. Guide de excursion des 7me Congress Geologique International, 1897.

sulphide, there are shells of a larval pelecypod which probably descended to this depth during its meroplancton stage. Diatoms are also found in the dark blue mud that contains, besides iron sulphide, carbonate of lime in fine grains. All these instances, associated with the fact that the diatom tests are more resistant to alkali than generally supposed, indicate the persistence of diatom frustules even in deposits charged with much organic substance, where water is apt to become alkaline.

The calcareous shells of molluscs are rather abundant near the surface of the mud deposit. They decrease in number with increasing depth, and 15 feet below the surface of the mud deposit they are practically absent.

This mud so closely resembles a certain kind of shale occurring in the Tertiary oil measures of Japan that they are indistinguishable under the microscope. This type of shale, which is more or less terrigenous, is often found interstratified with the marine diatomaceous or tuffaceous shales.

TABLE I.

ANALYSES OF SALTS EXTRACTED FROM THE MUDS.

Muds were first dried at 105° C., then extracted in a Soxhlet apparatus with water for 9 hours.

Total.		Cl.	SO_4.	Ca.	Mg.	Na, K.
Muds.	Salts.					
6 ft.....	3.27%	1.60%	0.02%	0.11%	0.18%	n.d.
9 ft.....	4.23	2.44	1.49	0.08	0.09	"
12 ft.....	4.29	2.11	1.81	0.05	0.09	"
15 ft.....	5.25	2.48	2.25	0.07	0.16	"

It is clear from Table I., that the amount of water-soluble Cl, Mg, Fe and SO_4 increase with increasing depth, suggesting some process of decomposition that takes place in the deeper zones where the water contained is almost stagnant and consequently low in oxygen content.

As shown in the Table III., the amount of " soluble silica " increases rapidly with increasing depth. This suggests that the

"colloidal silica" is derived from diatoms, although other features could account for it equally well. At any rate, the increase of "colloidal silica" with increasing depth unquestionably shows some interaction taking place in the deeper zones between the organic and inorganic ingredients. This suggests the fate of organic matter that becomes buried in sediments.

TABLE II.

ANALYSES OF SALTS EXTRACTED FROM THE MUDS WITH CONC. HCL.

The insoluble residue from the above extracted by conc. HCl in an Erlenmeyers flask furnished with a reflux condenser and placed on a hot water bath for ten hours.

Muds (Depth in Ft.).	SiO_2 %.	Fe_2O_3.	Al_2O_3.	CaO.	MgO.	SO_3.	P_2O_5.	Ig. Loss.	Residue.	Total.
6.....	0.13	6.80	9.10	1.89	1.64	0.92	tr.	11.22	68.28	99.98
9.....	0.10	5.49	9.49	0.88	1.48	0.83	tr.	10.57	70.83	99.67
12.....	0.20	5.48	8.92	0.97	1.40	0.92	tr.	10.07	68.82	99.02
15.....	0.09	5.76	9.00	0.82	1.59	0.76	tr.	12.23	69.50	99.75

TABLE III.

PERCENTAGE OF "SILICA" SOLUBLE IN ALKALI, AND OF "CLAY" DECOMPOSED BY CONC. H_2SO_4 AND NAOH.

2 gr. of the residue from the above (Table II.), boiled for five minutes in a Pt. dish with 20 cc. of Na_2CO_3 solution saturated at 31° C.

Muds (depths in Ft.).	"Silica" Soluble in Na_2CO_3.	"Clay Substance" Decomposed with H_2SO_4 and NaOH
6	7.48%	66.39%
9	10.01	64.83
12	18.27	63.83
15	20.27	67.19

TABLE IV.

CHEMICAL COMPOSITION OF THE MUD TAKEN FROM A DEPTH OF 9 FT.

SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	So_3	P_2O_5	Na_2O K_2O	Ig. Loss	Total
61.73	9.65	14.23	1.67	1.88	nd.	nd.	nd.	10.59	99.75

Note: Method of the analyses applied, except for IV., approximately after "rational analyses," but more or less modified. The analyses were made by Tsugio Yagi in the Institute of Petrology, Tohoku Imp. Univ., Sendai, Japan.

When these muds, after being dried at 50° C. for one hour, were washed with chloroform in a Soxhlet apparatus for 5 hours and the residue treated with benzene oil for 5 hours, and the residue from it distilled in a fused silica tube, the following results were obtained:

Depths in Feet.	Extract by Chloroform.		Extract by Benzene Org. subst.	Distillates (Bitumen).	Total of Organic Substance.
	(Sulphur.)	(Org. Subst.)			
6.....	0.12%	0.06%	0.04%	0.04%	0.14%
9.....	0.15	0.07	0.03	0.03	0.13
12.....	0.12	0.07	0.03	0.04	0.14
15.....	0.11	0.12	0.02	0.05	0.19

It is interesting that the muds are rather rich in free sulphur that can be extracted by chloroform. The results also show that the content of organic substance is greatest at a depth of 15 feet, as is the case in the lagoon deposits of Kahoku.[32] These examples show that the organic matter in ordinary sediments by no means decreases with increasing depth as is sometimes stated.

The extracts are yellowish brown in color and solid at room temperature; their melting points range between 45° and 75° C.; they turn black when boiled with diluted H_2SO_4. These substances are mixtures and, at least in part, most probably fatty derivatives, because under experimentation they yielded unquestionably fatty substances.[33]

Furthermore, small amounts of apocrinic acid (Muller's) and so-called humic acid in these organic substances were demonstrated and the presence of the hymatomelanic acid of Hoppe-Seyler was detected.

Considering the state of preservation of the water grasses in

[32] See reference, note 11.

[33] Treated with alcoholic potash, distilled, addition of concentrated brine, precipitation with HCl and boiling. Compare the theory advocated by Künkler and others that petroleum is derived from fatty remains of organisms through saponification by $CaCO_3$ solution (bicarbonate solution ?). It has been experimentally proved that petroleum can be obtained by distilling the calcium soap of certain fish and vegetable oils (Künkler u. Swedhelm: *Seifensiederzeitung*, s. 1285, 1341, etc., 1908; Hoppe-Seyler: *Naturwiss. Rundschau*, s. 82, 1890, etc., etc.).

the deeper zones of the muds, and that all the organic matter is sadly macerated, it is probable that the organic substances deposited in the mud were first subjected to the ordinary process of decomposition. As the supply of oxygen became restricted, the process of fermentation, or anaerobic decay, seems to have replaced ordinary (aerobic) decomposition. Thus, a mixture of organic and inorganic colloids results.

In this connection the writer may recall the summary of various modes of decay of organisms and the corresponding decomposition products given by Stremme, who also consulted the opinions of Potonié and Ramann. According to him, the decomposition products depend mainly upon the conditions under which the decomposition takes place, such as the peat-forming process (Vertorfung); the humus-forming process (Vermoderung) and so forth. But it must be borne in mind that the original materials that give rise to humus or peat are mostly of vegetable origin. With a different original substance, even by the same process, different products may result. For example, through the humus-forming process, a so-called ulmine substance is produced from animal substances.

In this connection, the writer is reminded of the theory advanced by Rae [34] that oil possibly originated from " ulmo-humic " substances contained in shale. In view of the somewhat vague meaning of the word " ulmo-humic " the writer is not quite certain whether or not the " colloidal organic substances " he thus obtained may even approximately be represented by this word. Such words as " ulmo-humic " and " kerogen " are certainly objectionable from the terminological point of view, as suggested by Washburne.[35] Their use is to be avoided if possible, and further study of such indefinite substances may probably enable us to do so.[36] Meanwhile, because of the lack of appropriate words to designate such indefinite mixtures of organic substances

[34] Rae C. C., *Bull. Amer. Assoc. Petrol. Geol.* vol. vi, No. 4, pp. 333–341, 1922.

[35] Washburne, C. W., *Bull. Amer. Assoc. Petrol. Geol.*, vol. vii, No. 4, pp. 440–442, 1923. He suggests the use of the word " organic colloid " instead of " ulmo-humic."

[36] Oden, Sven. Huminsaure, *Kolloid Chemie,* Beihefte, Bd XI., 1919.

found under approximately similar conditions, there seems no alternative but to use these words tentatively. By the word kerogen is here meant more or less indefinite mixtures of organic substances which give rise to petroleum (and to fixed carbon, gases and vapors, sulphur and nitrogen compounds, etc.) on distillation.

Any organism, generally speaking, may be regarded as consisting largely of three kinds of materials,—fatty, cellulosic and albuminous. On the decomposition of organisms, the albuminous substances seem most readily decomposed, probably leaving sulphur in the mud, as in Shiogama Bay. The fatty substances are supposed to be converted into fatty acids, which are resistant to sub-aquatic anaerobic decomposition. Cellulosic substances, depending on the conditions under which the decomposition takes place, result in humus or peat. Under sub-aquatic anaerobic decomposition, cellulosic substances are known to alter to fatty acids only through the process called methane- or hydrogen-fermentation. In both kinds of decomposition CO_2 gas is evolved. This fact probably explains the decreasing content of calcareous shells (not necessarily the $CaCO_3$ content) with increasing depth. Thus, the final products of the subaquatic anaerobic decay of organic substances are considered to be largely fatty derivatives. The results of the examinations of the muds from various water areas as already stated, also justify this conclusion.

Thus, the analyses of the mud of various water areas and fossil mud beds indicate that all the organisms deposited under water areas suffer from a peculiar mode of decomposition that results in the production of homogenous organic substances that seem to be a mixture containing fatty derivatives for the greater part and so-called humus, wax, resin etc. to some extent. These organic substances are found intimately mixed with the matrix of the muds, so as to form a colloidal mixture. These organic substances naturally differ chemically in the different kinds of water areas. But they are fairly similar in appearance and in state of preservation (being colloidal) and even somewhat similar in chemical character, especially when the muds are deposited under

similar kinds of water areas. The above mentioned facts suggest the probable fate of most organisms that are deposited in water areas.

The siliceous or calcareous shells of organisms may be preserved in the deposits as such, whereas the organisms without such skeletons may be entirely obliterated except for the organic colloids mentioned above.

POSSIBILITY OF OIL BEING DERIVED FROM THE WHITE DIATOM EARTH OF THE MONTEREY FORMATION.

It seems unquestionable that the oil in the Monterey shale was derived from organic substances contained in the shale. But how can it be proved that the shale contained organic substances that contributed to the oil? The examination of various sediments, recent or old, shows that the fossils retained in the sediments do not represent the true proportion and the kinds of organisms originally contained in them.

The very beds from which "diatom wax" was supposed to have been obtained and upon which the diatom theory of the origin of petroleum is based have been shown by Potonié not to be true diatomaceous earth. Thus, abundance of diatoms in the Monterey shale does not necessarily indicate that diatoms alone thrived in the water areas in which the shale was deposited. Nor are fossils alone sufficient to prove the shale to be of organic origin, or to have yielded petroleum. It is essential that the shale contain, besides fossils, remnants of the original organic ingredients, such as carbonaceous, bituminous or kerogenous substances, and certain minerals and matrix of sapropelic origin.

The diatomaceous shale of the upper zones is bleached white and devoid of organic substance but for the oil or asphaltic substance which was undoubtedly introduced from the strata below. No sapropelic mineral and matrix are found in most of the shale of this type, although some of the diatomaceous shale contains considerable fine silt. That the diatomaceous shale of the Truckee formation is exactly like the white, softer variety in California has already been mentioned. According to Ander-

son,[37] " it differs chiefly in the fresh water instead of marine character of the diatom species that compose it. None of the porcelaneous or flinty beds characteristic of the Monterey and other formations of California have been found there. . . . No definite reason can be given for the failure of the diatomaceous beds of the Truckee formation to produce petroleum, while the diatom content of the original petroliferous formations in California is thought to have been the source of much of the oil there. Some persons have expressed the opinion that oil is never produced in fresh water beds. The reason for its absence in this region is probably not to be sought, however, in the inability of fresh water organisms to produce oil, but rather in the manner in which the beds were laid down and conditions to which they were subjected after their deposition. The diatomaceous beds of the Truckee are thought to have been formed in marshes and shallow bodies of water, the nearness of the sediments to the surface causing them to be exposed to conditions favoring decomposition and escape of organic matter they contained."

The opinion of Anderson, so far as cited above, seems reasonable. Diatomaceous earth of the Truckee probably contained organic substances either of diatoms or of other organisms, as is the case in that of Tochibori. The unstable condition of diatomaceous earth to retain organic components undoubtedly favored decomposition of the latter, although the formation is estimated to be quite thick, some 400 ft. in maximum.[38] Scarcity of the colloidal clay or silica in diatom earth undoubtedly is responsible for less persistency of its organic content than in clayey or cherty shale. At any rate, there is no reliable evidence for the supposition that this kind of diatomaceous shale retained sufficient organic substances, either of diatoms themselves or of other petroleum-yielding organisms, until the shale was distilled by natural process, to produce petroleum.

Furthermore, it seems questionable whether the planctonic diatoms become buried in sediments with rich organic contents,

[37] Anderson, R., U. S. G. S. Bull. No. 381, Pt. 2, Universal Fuel, pp. 475–493.
[38] Louderback, G. D., *Bull. Geol. Soc. Amer.*, vol. 18, pp. 663–669, 1906.

although they are known to accumulate oil in their bodies at certain periods during their life history.

In this relation, readers are referred to the conclusions given by Herdmann,[39] who investigated the life of plancton in the ocean near Ireland for over ten years. According to him, diatoms, in certain seasons, at a period of maximum development, are found to be displaced by another form of plancton such as copepods, which probably live on diatoms as their food. The great development of the plancton, especially when copepods become rich in fatty substance, results in attracting large numbers of fish. It is also reported that diatoms, when the conditions of salinity or temperature of the sea water become unfavorable for them, sink together to the bottom of the sea and reproduce other bodies adopted to the new conditions: thus producing an accumulation of practically discarded tests of diatoms. As the white diatomaceous shale of the Monterey formation is devoid of any organic substance, there are no definite data to overcome the presumption that the diatoms may be merely the discarded tests practically devoid of organic substance. However, considering that areas which seem to be the remains of higher plants are sometimes found in the diatomaceous shale, and there is some resemblance of the latter to those of the Truckee formation and of Tochibori, it is probable that the white diatomaceous shale of the Monterey formation contained originally organic substances, either of diatoms themselves or of other organisms, or both, but caused to disappear afterward by weathering.

It is a well known fact that diatoms are the chief element in the plancton which can supply oxygen to animal plancton and consume the CO_2 given off by the latter. One can hardly imagine a water area in which diatoms alone thrive throughout the year.

It is also stated that a diatom may preserve its organic content in virtue of its test. It is clear, however, that the main advantage assigned for the test is not to seal up its organic content in it,

[39] Herdmann, W. A., "The Distribution of Certain Diatoms and Copepoda throughout the Year." *Jour. Linn. Soc.*, Botany, vol. xliv, pp. 172, 1918. See also, Nathanson, V., "Zirkulation u. Planktonmaxima in Mittelmeer," *Intern. Rev. d. gesam Hydrobiol. u. Hydrogr.*, 1009.

but by use of it to perform the function of the protoplasm. And the supposition that the test may serve to retain the protoplasm after its death is without ground. Certain liquids, impregnating diatomaceous earth from without, however, may sometimes be retained in virtue of the capillary and absorptive action, unlike the organic content of clayey and cherty shales, which in diatomaceous earth is apt to be weathered away, due to its porosity. This is an explanation for the fact that most diatom earths are bleached white, devoid of organic substance, even when the diatomaceous shale, containing much fine silt and other types of shale interstratified with the white diatomaceous earth, contains some organic substances.

As all theories of the origin of petroleum embrace much speculation, it seems impossible to discuss in detail how the oil was formed in the Monterey formation. An essential condition, however, is that the petroleum yielding substances should not be removed from the shale before the process of "natural distillation" takes place in the formation. Some bitumens have been reported to be biochemically produced under certain climatic and geographic conditions.[40] But liquid hydrocarbon oil from wax, resin, oil, and fat, both of animal and vegetable, and their derivatives, as well as solid bitumen and pyrobitumen, may be obtained so far as we know only by distillation.[41] Supposing that the oil was derived from the diatomaceous earth now bleached white, the natural distillation should take place at an earlier stage of the sedimentation, because diatomaceous earth is so apt to be bleached white, losing its organic content, as already stated. And it is probable that at that stage of the sedimentation, some organic substances which can not be converted by distillation to petroleum, were not entirely removed from its organic contents. Experi-

[40] Rothpletz, A., "On the Formation of Oölite," *Botanische Centralbl.*, No. 35, pp. 265–288, 1889, etc.; Kalkowsky, E., Oölith u. Stromatolith in Norddeutchen Budsandstein, *Zeitschr. deut. geol. Gesellsch.*, s. 668–725, 1908, etc.; Clarke, *op. cit.*, note 18. Haseman, J. D., "The Humic Acid Origin of Asphalt." *Bull. Amer. Assoc. Petrol. Geol.*, vol. 5, p. 75, 1921.

[41] Engler, C., *Ber. Deutsch. Chem. Gesell.*, vol. 21, s. 1816, 1888; vol. 22, s. 592, 1889; *Zeitschr. Petrol.*, vol. VII., s. 399, 1911; see also references, notes 33 and 18.

ments [42] show that fixed carbon or a substance rich in carbon content is produced from the distillation of such substances. And a sediment, once stained with such carbonaceous substances, is with difficulty bleached white, due to the chemical inertness of carbon. A slight amount of oil, even one per cent. by weight of diatomaceous earth, is sufficient to color the earth black, if the oil is homogeneously soaked in the earth by means of a suitable solvent, and distilled. It is improbable, therefore, that diatomaceous earth devoid of any trace of organic component, either carbonaceous or bituminous, can be the parent bed of petroleum.

It is generally accepted that there are two stages in the formation of petroleum from organic substances: first, biochemical, and second, geodynamical.[43] Experiments suggesting the effect of dynamical disturbance on the process of the formation of petroleum have been reported by several investigators, including A. W. McCoy and F. Bergius. It is improbable, however, that petroleum may be produced by static pressure alone, unless heat is generated. In many places, petroleum is reported to occur in the zones geologically disturbed,—such as shattered or brecciated shale, faults, fissures, or strongly folding areas. A peculiarly "sheared" specimen of limestone from the Oil Measure of Japan was described by the writer.[44] All this suggests the rôle of the geodynamical process in the formation of petroleum.

There seems no trace of such disturbance in the soft, white diatomaceous shale of the Monterey fomation, though the harder shales predominating in the lower zones are often found highly brecciated. And it is improbable that the oil was derived from the diatomaceous shale of the upper zones in this manner.

In certain oil fields, as in Mexico and Japan, where intrusive sheets of igneous rocks are found intercalated in the oil formations, the rôle of the heat generated by the intrusive action of the igneous rocks, is to be taken into account. It is questionable, however, to what extent oil may actually be formed by this heat,

[42] See reference, note 23.

[43] Dalton, W. H., Econ. Geol., vol. 4, p. 603, 1904; White, David, *Jour. Wash. Acad. Sci.*, vol. 5, p. 189, 1915; *Bull. Geol. Soc. Amer.*, vol. 28, 1917, etc.

[44] *Op. cit.*, note 11, Pl. V., Fig. 1.

because of the poor thermal conductivity of the shales associated with oil formations. That the thick-bedded diatomaceous shale of the Monterey was distilled by such direct heat to produce the oil is also improbable.

In the oil fields containing igneous rocks almost contemporaneous with the surrounding sediments, it is probable that the greater part of the oil was produced through a process somewhat resembling the artificial distillation of oil by the use of superheated steam.

The super-heated steam or water, accompanied by relatively high pressure, during the distillation of the organic content of sediments into oil, may force its way through fissures and crevices until it finally precipitates in porous parts of the formations and in the upper zones where pressure and heat are moderate. Superheated steam probably facilitates the migration and accumulation of petroleum.

Compared with the distillation by direct heating, that by use of super-heated steam produces much less carbonaceous residue in the "spent shale." The theory also seems to account for the occasional lack of any sediment colored by carbonaceous substance in the oil-bearing formations, and also many other phenomena of various occurrences of petroleum. There seems to be no remarkable inconsistency between this theory and the existing features of various oil deposits.

The writer is uncertain whether the theory is applicable to the oil formations in California, and to other oil fields of the world where no igneous rock is found. Even in such places, some chemical or physical agency may easily be assigned for the origin of heat to obtain water heated to a temperature of about 300° C. At any rate, even if we suppose the oil of California to have been produced in this manner, it is improbable that the white, soft diatomaceous shale of the Monterey formation contributed very much to the oil. In a thick bed of such soft and friable sediment, any kind of an opening due to the geodynamical disturbances such as a fault or fissure would soon be closed, so that migration of

oil from the strata below may only be transient. When such an "open passage" for the migration of oil is closed, the vapor of the oil and water may force their way so far as possible to the porous beds of the overlying formations, resulting in a sediment homogenously soaked with the oil. Except for the "bituminous shale," bituminous substance is not found in the white diatomaceous shale, which is sometimes thickly developed.

Finally, the diatomaceous deposits discussed above are found closely related, directly or indirectly, to tuffaceous deposits. This is true of the Monterey formation as well as of the Tertiary oil measures of Japan. It is generally considered that diatoms thrive in water charged with clayey substance, and fine detritus of volcanic ash may serve as well as clay particles. Diatoms abound also in water areas in the vicinity of volcanoes. The presence of the tuffaceous material thus probably explains the special abundance of diatoms producing the thick diatomaceous beds, which seem to have accumulated rapidly. Abundance of diatoms may in turn result in stimulating the development of other forms of life; and all of them, whether vegetable or animal, may contribute more or less to the organic constituents of the sediments. Deposits of pure marine diatoms probably represent the areas of deposition beyond the reach of inorganic sediments, either pyroclastic or transported, although most of the diatomaceous part of the Monterey shale contains a considerable amount of fine silt.

The results of the study of various diatomaceous deposits by chemical, microscopical and biological methods indicate that:

CONCLUSIONS.

1. Organic substance in diatomaceous deposits is not mainly derived from diatoms but from other organisms not represented as fossils.

2. Purest diatomaceous earth occurs in the upper zones of the Monterey shale, whereas the oil is associated with the siliceous and marly shales of the lower part, which were probably deposited under different conditions of sedimentation.

3. No sign is left in the soft diatomaceous earth to suggest that it was distilled to produce oil.

4. Even though oil in California was produced by the super-

heated steam process as in Japan, it is improbable that the pure diatomaceous shale contributed much to the oil.

5. It is believed that petroleum was derived from organic remains similar to those which were obtained from muds deposited in the sea partially cut off from the ocean by a barrier.

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COINCIDENT VARIATIONS OF TYPES OF MINERALIZATION AND OF COAST RANGE INTRUSIVES.[1]

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THIS paper is an abbreviated and modified summary of the scientific portion of a chapter covering a general survey of the mineral deposits of southeastern Alaska prepared by the writer.[2] It is based upon five seasons' field work by the author in a geologic reconnaissance and study of the mineral deposits of southeastern Alaska, upon an unpublished manuscript report by Theodore Chapin based on three seasons' field work in the southern Ketchikan district, another unpublished manuscript report by F. E. and C. W. Wright on the Glacier Bay area, and on a careful study of the literature.

Many mineral deposits are associated with the Coast Range intrusives of southeastern Alaska and British Columbia. Assuming that this association is the result of a genetic relation, we have the problem of attempting to evaluate the proper weight which should be given to such factors as the mode of occurrence of the igneous body; the chemical and physical character of the country rock; the temperature, pressure, and time elements; and the composition, and the stage and kind of differentiation of the magma; in producing the mineralization and the variations in type of mineralization found. It is this problem which is discussed here, with special emphasis upon an attempt to see if there is any correlation between the kinds of mineralization and the kinds of associated intrusives.

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[2] To appear in "The Geology and Mineral Deposits of Southeastern Alaska," by A. F. Buddington and Theodore Chapin, as a publication of the U. S. Geological Survey.

COAST RANGE INTRUSIVES.

The Coast Range intrusives, according to their mode of occurrence and composition, may be classified in six groups: (1) ultrabasic and gabbroic rocks including such types as hornblendite, pyroxenite, dunite, troctolite, wehrlite, saxonite, norite, etc., which are common as small stocks and dikes throughout the Alexander Archipelago; (2) mediosiliceous types such as gabbro-diorite, diorite, monzodiorite, and quartzose diorite, which are the predominant intrusives in a belt to the west of the main Coast Range batholith; (3) a small volume of sodic leucocratic differentiates associated with the rocks of group (2) and with stocks of quartz diorite, and occurring locally as marginal variants or as offshooting small stocks and dikes; (4) siliceous types such as quartz diorite, granodiorite, and quartz monzonite, which are the predominant types in the main Coast Range batholith; (5) pegmatite and aplite dikes; (6) lamprophyre dikes.

The lamprophyre dikes are in general of a spessartite type, with an unusually large percentage of plagioclase and a correspondingly low percentage of brown hornblende and occasionally augite. They are usually later than the ore bodies. The pegmatite and aplite dikes show no unusual features, and are composed of feldspar and quartz with a little mica or hornblende and sparse accessories. They are older than the ore bodies. The writer has found no general significant relation between the mineral deposits and either group of these dike rocks.

ASSOCIATIONS OF METALLIFEROUS MINERALS AND ROCKS.

The well established rules for the very close association of certain kinds of metalliferous minerals with certain types of ultrabasic rocks are well exemplified in southeastern Alaska. For example, chromite has been found as disseminations through dunite, though not in commercial quantitites; pentlandite is absolutely restricted to, and is actually known to occur only within, the magnesium-rich rocks of the ultrabasic or gabbroic group; chalcopyrite is associated with pentlandite wherever the latter occurs and is common as small blebs or veinlets within some of the

amphibolites and gabbros; ilmenitic magnetite tends to occur in large concentrated amounts only within the hornblendites and aluminous pyroxenites; palladium-bearing bornite deposits have been found within pyroxenite; and apatite tends to be concentrated with the hornblendites.

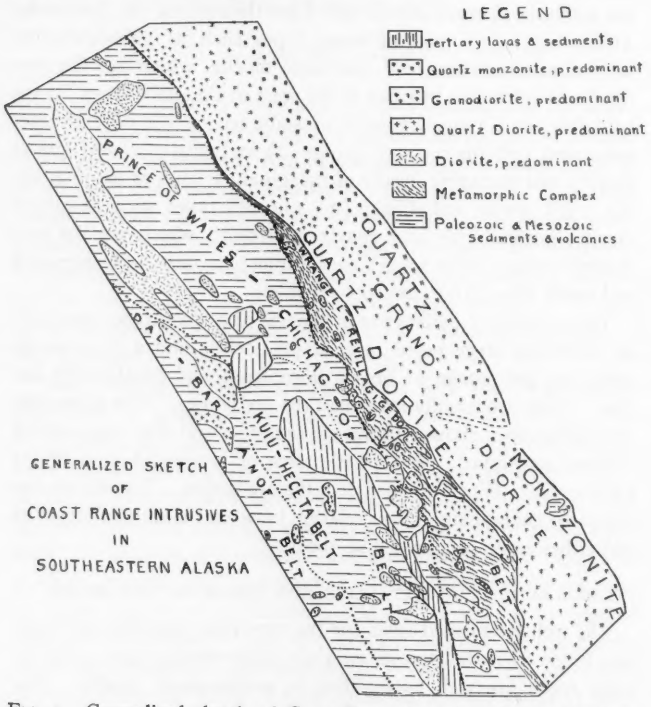

FIG. 1. Generalized sketch of Coast Range intrusives in southeastern Alaska.

Nickel-copper lodes at Bohemia Basin, Yakobi-Island, occur in norite or bronzitite segregations within the norite; at the Alaska Nickel mines on Fleming Island, in hornblende gab-

bro and norite; at Snipe Bay, Baranof Island, in an amphibolite dike with a high percentage of ilmenitic magnetite; at Tenakee Inlet, Chichagof Island, in a schistose basic dike; and at Funter Bay, Admiralty Island in a troctolite dike. The sulphides consist predominantly of pyrrhotite with a little pentlandite and chalcopyrite. They may form practically solid lenses of sulphide, or they may be disseminated as blebs throughout a considerable portion of the rock. The distribution of the sulphides throughout the igneous rock mass in which they occur is not uniform, but irregular and local. The sulphides are interpreted as having been originally more or less homogeneously in solution in the molten magma. On cooling of the magma, the sulphides separated as immiscible drops and were concentrated locally to varying degrees. The disseminated type of ore represents a relatively slight concentration of the sulphides where the latter remained molten longer than the silicate portion and crystallized at a late stage interstitial to the silicates. The more concentrated or solid sulphide masses represent a more complete concentration or segregation of the sulphides, which remained molten longer than the silicate magma, and through subsequent movements came to bear a vein-like intrusive relation to the country rock. Such variation in relations need not, therefore, be interpreted as indicating more than the complex phenomena which may result in the solidification of a single magma essentially in place. In the Tenakee prospect the sulphides, as they now occur, are definitely later than the dike which contains them; for they occur in part as seams in a sheared zone within the dike, and in minor part as metallized quartz stringers in the shear zone. Pyrrhotite, pentlandite, and chalcopyrite occur in the quartz-calcite stringers.

Analyses for nickel have been made on a number of pyrrhotites from contact metamorphic and fissure vein deposits associated with diorites or more alkalic-siliceous rocks, but they show only 0.1 to 0.2 per cent. of nickel and a trace of cobalt.

Magnetite with a little associated ilmenite forms both disseminated deposits, veinlets, and dikes in bodies of pyroxenite

and hornblendite. In the disseminated type, the magnetite and ilmenite occur as irregular shaped blebs interstitial to the silicates. The iron oxides may form up to 30 per cent. of the rock, equivalent to about 20 per cent. metallic iron. Such a disseminated type of rock occur in considerable volume near Union Bay on the Cleveland Peninsula and near Haines. At Snettisham there is a dike 6 feet wide of practically solid ilmenitic magnetite in hornblendite. Small veinlets of ilmenitic magnetite are also common in the surrounding rock. The ilmenite occurs in part as separate grains and in part as lamellæ of microscopic size parallel to the parting planes of the magnetite. At Snettisham, the ilmenite in a typical specimen constituted about 8 per cent. of the ore. The ilmenitic magnetites appear to be associated with the diallage varities of pyroxenite rather than with the diopside pyroxenites.

The palladium-bearing bornite deposit of the Salt Chuck mine on Prince of Wales Island has been described by Mertie.[3] The ore occurs in pyroxenite with gabbroic variants. The ore minerals consist of copper sulphides, distributed in grains, small patches, and veinlets as ore shoots in the pyroxenite. Bornite is the chief copper mineral, but a small proportion of chalcopyrite also occurs locally. The ore deposit is believed by Mertie to have formed later than the containing country rock, and is not a primary magmatic concentrate as some of its features seem to indicate.

The same metalliferous minerals associated with the ultrabasic group have a much less marked tendency towards migration as compared with the more siliceous-alkalic group, and this is well shown by magnetite and chalcopyrite. In the pyroxenites, magnetite occurs predominantly in disseminated interstitial blebs even where it forms up to 30 per cent. of the rock. In the hornblendites, which on the basis of considerable data are believed to owe their origin in part to a relatively high percentage of mineralizers, the magnetite may occur as veinlets and vein-dikes, but still re-

[3] Mertie, J. B., Jr., "Mining in the Juneau and Ketchikan Districts, 1919," U. S. Geol. Survey Bull. 714, pp. 121–127, 1921.

stricted to a position within the hornblendite mass. In the case of the diorite, quartz diorite, and granodiorite, however, the magnetite, with some specularite, occurs locally in large bodies as replacements of the country rock near or adjacent to the intrusive. mass. These phenomena indicate that as the content of mineralizers increases there is a corresponding increase in the mobility and migration of the magnetite. Chalcopyrite shows a similar series of phenomena. Associated with a little pentlandite and a relatively large amount of pyrrhotite, it forms disseminations and solid lenses within certain types of gabbroic and ultrabasic rocks. Within certain gabbroic rocks it also forms veinlets in local fractured zones. Chalcopyrite has a greater tendency than magnetite, however, to occur in vein-like form in gabbroic and ultrabasic rocks. Chalcopyrite also, like magnetite, where associated with dioritic and granodioritic rocks exhibits the results of greater mobility than where associated with basic and ultrabasic rocks, inasmuch as it occurs typically in the country rock as contact deposits adjacent to the intrusive body, or in shear zones or impregnation deposits at considerable distance from the intrusives. Here again the chalcopyrite also shows a relatively greater tendency towards migration and to move out and farther away from the same general magma than the magnetite.

The genetic association of certain kinds of mineralization with certain kinds of ultrabasic and gabbroic igneous rock is clear and definite. The metalliferous minerals or solutions in the cases described have not traveled outside of the igneous rock which gave them birth. In the case of the more siliceous and more alkalic rocks, however, the problem of endeavoring to relate a kind, or group, of kinds, of mineralization to a kind of igneous rock becomes immensely more complicated. The metalliferous solutions may wander far from their parent magma, external factors may thereby have great influence, a differentiation may take place within the solutions themselves, and there may be overlapping effects from the different stages of differentiation reached by the different bodies of magma within a limited region or by the magma within the same stock or batholith at successive times.

It so happens that in the region under discussion there are large belts of country within which a certain type of siliceous igneous rock predominates. This affords an opportunity to compare the kinds of mineralization within these belts, and to see whether there is any correlation between them and the kinds of intrusives. Other factors, however, are so important or dominant that it is difficult to reach definite conclusions, especially as, after all, our information as to either the intrusives or the mineral deposits of this region is very scanty. Nevertheless, there are certain tentative ideas suggested to the writer by a study of the phenomena referred to, which are presented here.

ROCK BELTS.

The Coast Range intrusives[4] of southeastern Alaska and of that portion of British Columbia adjoining on the east may be grouped into six belts, using the abundance, mode of occurrence, and the predominant type of intrusive as criteria. From the southwest to the northeast (Fig. 1) these six belts are called by the writer the (1) Dall-Baranof, (2) Kuiu-Heceta, (3) Prince of Wales-Chichagof, (4) Wrangell-Reviliagigedo, (5) Coast Range batholith, and (6) eastern border or interior belt.

Dall-Baranof Belt.—The Dall-Baranof belt is not very well known, either with respect to the character of the intrusives or the character of the mineral deposits. There are no operating mines in this area, and there are insufficient data for discussion.

Kuiu-Heceta Belt.—In this belt, intrusive stocks are rare and metalliferous mineral deposits are equally sparse. Indeed, there is not a single metalliferous mineral prospect in the belt which is worthy of note. Metamorphism is at a minimum, and beds as old as Ordovician carry identifiable fossils.

Prince of Wales-Chichagof Belt.—Here, the country rocks consist of graywacke, limestone, tuffs, slate, and schistose greenstone. There are no crystalline schists or marbles except immediately adjacent to intrusive bodies. Intrusive stocks and small

[4] Buddington, A. F., "Coast Range Intrusives of Southeastern Alaska." To appear in *Journal of Geology.*

batholiths are abundant and consist predominantly of diorite, quartzose diorite, and monzodiorite, with subordinate quartz diorite and granodiorite. The average composition of 65 specimens from the belt is that of a quartzose diorite (Table I, No. 1). The predominant metalliferous minerals are the oxides and sulphides of iron, chalcopyrite, and native gold. The iron and copper minerals occur to the largest extent in contact deposits, but the copper minerals also occur to some extent in veins of replacement, impregnation, and shear zone type. The gold occurs predominantly in veins with a quartz gangue with associated sparse sulphides. Ores of silver-lead, and zinc have been observed at several localities within this belt, but they are apparently subordinate to the iron, copper, and gold deposits.

Wrangell-Revillagigedo Belt.—To the northeast of the Prince of Wales-Chichagof belt is the Wrangell-Revillagigedo belt. The country rock here consists of a metamorphic complex comprising phyllites, crystalline schists, injection gneisses, and intercalated marbles. The intrusives are abundant as small stocks and batholiths, and consist almost exclusively of quartz diorite. Metalliferous deposits in this belt are relatively rare, though quartz veins are abundant and gold is predominantly the metal sought. Only two copper deposits are reported in this entire belt. The gold veins are mainly in the outer portion of the belt of metamorphic-complex. The metamorphic intensively recrystallized rocks represent relatively high temperatures and pressures; and it seems probable that these are important, if not the most important, factors in explaining the relative absence of metalliferous deposits. It is also probable that the character of the rocks is an important factor. Many zones impregnated with sulphides of iron carrying a little gold occur in the schists, and it is possible that the gold values were thus disseminated through a large volume of rock rather than concentrated in workable veins. The Wrangell-Revillagigedo belt probably overlies an upward outward major bulge in the batholith such that its upper surface is predominantly at only shallow depths beneath the present topography, and the exposed stocks and batholiths are equivalent to hills on its surface.

The country rock above would therefore be relatively highly heated by conduction and highly heated vapors and solutions, and the metals might not be deposited in concentrated form until a less schistose and cooler region were reached—a region now eroded.

The Wrangell-Revillagigedo schist and gneiss belt, with its associated abundant intrusives, dies out towards the northwest and its place is taken by the Juneau gold belt, with rocks comprising slate, graywacke, dynamically metamorphosed schistose greenstones and relatively sparse associated intrusives similar to those of the Prince of Wales-Chichagof belt. This decrease in number of intrusives, their change in character, the decrease in metamorphism, and the practical disappearance of aplitic injection gneiss, are explicable on the assumption that the Wrangell-Revillagigedo bulge in the batholith has a subsurface irregular shelf or terrace-like form which drops away relatively abruptly northwest of Thomas Bay and leaves the western border of the batholith in the Juneau district with a very steeply plunging slope, which carries it rapidly to great depths beneath the overlying country rock. The rocks of the Juneau gold belt would, therefore, have been in a cooler environment than those to the southeast; what intrusive bodies there are would be, in part, a long way vertically from their source; and the same would be true of the auriferous quartz veins. Such a hypothesis would suggest that the temperature factor was the important one, and that the ore deposits and exposed dioritic and sodic intrusives were both genetically associated with a common deeper-seated magma. Copper deposits are rare here, and this may in part be due to the relatively few intrusive stocks and in part to the character of the country rocks. A deposit does occur in limestone and schistose greenstone at Pt. Astley and at William Henry Bay on Lynn Canal, both at considerable distance from the border of the batholith.

Coast Range Batholith.—The Coast Range batholith, between the Stikine River and Portland Canal, a distance of 150 miles, appears to consist, so far as a geological reconnaissance shows, in general of a belt of quartz diorite along the southwest, granodior-

ite with local subordinate quartz monzonite or quartz diorite bands in the core, and a belt of quartz monzonite along the northeast border.

Very few mineral deposits have been discovered in association with the quartz diorites of the western portion of the batholith. There is a copper-zinc deposit at Tracy Arm, and the zinc and silver-lead deposits at Groundhog and Glacier Basins east of Wrangell. But the latter two deposits are associated with quartz porphyry sheets, and it might be questioned whether they are genetically connected with the quartz diorite or with the porphyry sills. A probable interpretation is that both are genetically connected with the original quartz diorite magma. There is a silver-lead deposit on the Whiting River. To the southeast[5] near Vancouver in British Columbia, there is a zinc deposit with some galena at the contact with a basic marginal variant of the quartz diorite, and between Powell River and Lund there is a prospect in which zinc is the prevailing element. Copper deposits are also known. The data are too few to afford adequate evidence as to what is the predominant type of metallization in association with the western portion of the batholith. The occurrence of two contact metamorphic zinc deposits is in marked contrast to the typical copper-iron contact deposits of the Prince of Wales-Chichagof belt. The few data there are suggest that zinc and copper, and to a lesser extent gold and silver-lead, prevail.

The core of the batholith and its northeastern portion are composed of granodiorite and quartz monzonite, with the former predominant at the core and the latter forming the northeastern portion. There is considerable variation in the degree of metamorphism of included blocks of country rock. Some of the smaller ones have been changed to crystalline schists and injection gneisses, but some of the larger ones still consist of dynamically metamorphosed schists and associated slates, graywacke, limestone, conglomerate, etc. Relatively few metalliferous prospects are known, though this is in part due to inaccessibility and lack of

[5] Brewer, W. M., "Some Ore Deposits of the Coast Range," *Trans. Canadian Inst. Min. and Met.*, vol. XXV., 1922.

exploration. The copper deposits at Anyox are the most important. Silver-lead and base metal (zinc, copper, and lead) veins are found along the Unuk and Iskoot Rivers. All of these deposits are in included blocks of country rock.

Interior Belt.—In the belt northeast of the Coast Range batholith, the country rocks consist of graywacke, argillite, slates, greenstone, and tuffs. The number of intrusive bodies varies markedly from northwest to southeast, and there is little information as to their exact character. There are a number of stocks known to be of granodioritic character. A number of important mineral deposits occur within this belt. Galena and tetrahedrite are far more abundant in many of the veins here than in any other belt. Gold and base metal (zinc, lead, and copper) lodes, however, are also prominent. Native silver, pyrargyrite, proustite, and argentite, are important ore minerals, but they are thought to have formed mainly through processes of secondary enrichment and are only in small part of primary origin. It is possible that arsenic, antimony, and tungsten, in addition to lead and silver, are relatively more abundant in this belt than elsewhere, but the data

TABLE I.

AVERAGE COMPOSITION OF COAST RANGE INTRUSIVES GROUPED BY BELTS.

	Andesine.	Potassic Feldspars.	Quartz.	Hornblende.	Biotite.	Accessories.	Augite.
Average of 65 specimens from Prince of Wales-Chichagof Belt	58	5	9.5	20.5	3.5	2.5	1
Average of 20 specimens from Wrangell- Revillagigedo Belt	53.5	6.5	19	8	11	2	
Average of 20 specimens from western portion of Coast Range batholith	53.5	2	20	11	11.5	2	
Average of 44 specimens from core of Coast Range batholith between Stikine River and Portland Canal	44	21	20	6	7	2	
Average of 16 specimens from eastern portion of Coast Range batholith between Stikine River and Portland Canal	37.3*	32.7	24.5	0.1	4	1.5	

* Oligoclase or oligoclase-andesine.

are inadequate to decide. The problem in this northeastern border belt is complicated by the fact that there are two ages of Jura-Cretaceous intrusives present in the Salmon River basin at the head of Portland Canal and that each is associated with metalliferous deposits. It is a question as to whether this is a local complexity, or whether there may also be two periods of ore deposition represented elsewhere along the eastern border of the batholith; and if so, to which period and with what kind of intrusive the various kinds of mineralization are associated. In British Columbia in this eastern belt there are also stocks of diorite present, with which gold quartz veins are associated.

RELATIONS BETWEEN ROCKS AND ORES.

From the foregoing discussion, it would appear that certain kinds of metallization are characteristic of certain belts, and that the changes in the predominant kinds of metallization from one belt to another are in part coincident with changes in the predominant kind or kinds of associated igneous rocks from one belt to another. But it does not prove whether the change in the kind of metallization is genetically related to the difference in stage of magmatic differentiation represented by the associated or underlying intrusives, or whether it is only one of a number of factors, or whether the relation is one of mere fortuitous coincidence and some other factor or factors have exercised the predominant control.

Lindgren[6] in discussing the mineralization accompanying the great batholithic intrusions of the Mesozoic extending from Lower California to Alaska, writes:

> Gold primarily and copper secondarily are the characteristic metals. Along the Pacific Coast, where there is little limestone in the intruded sediments, lead is practically absent, but in the interior, as in Nevada and Arizona, where the intrusions came into contact with Paleozoic limestone, this metal, with zinc, begins to appear. Silver is everywhere present, but scarcely ever important, except where lead appears.

In southeastern Alaska and British Columbia, so far as the

[6] Lindgren, Waldemar, "Mineral Deposits," pp. 920–921. McGraw-Hill Co., 1919.

writer's knowledge goes, there is no more limestone on the eastern side of the Coast Range batholith than on the western side, and the differences in mineralization on the two sides of the batholith are not in this region explicable upon the basis of different country rocks.

The physical and chemical characters of the country rock have, of course, played an important rôle in causing the localization of replacement ore deposits in the more easily replaceable beds, often greenstone, andesitic tuffs, or limestone; and in affecting the nature of the vein system in the case of fissure veins, exemplified by strong individual veins in diorite bodies on the one hand and stringer lodes in slates and thin bedded rocks on the other. But the capacity of the country rock to produce a difference in the kind of metallization does not appear to be very marked, except in local instances. In the Hyder district, however, there is a series of veins associated with a small batholith of granodiorite. Pyrrhotite is sparse or wholly absent in the quartz fissure veins within the granodiorite and the adjoining slates and argillites, but is common in the veins in tuffaceous graywacke, and is one of the major minerals in replacement veins in the greenstone portion of the country rock. The occurrence of pyrrhotite in the veins in the greenstone, as contrasted with pyrite in the quartz fissure veins in the granodiorite and slates, is possibly due to an influence of the country rock, though just how it operates is not clear.

All the metalliferous deposits associated with the Coast Range intrusives have been formed under intermediate to high temperature conditions as indicated by their associations, mineral content, and the type of alterations of the wall rock accompanying the introduction of the veins. They have been formed, as determined by actual observation, throughout a vertical interval of 5,000 feet and by inference throughout twice this interval, probably more. They must have crystallized at considerable depths for erosion has been taking place, so far as we know now, over the uplands ever since the time of intrusion of the Coast Range igneous masses in Upper Jurassic or Lower Cretaceous time. They are therefore intermediate to deep-seated and were formed under high pressure.

Schofield[7] has discussed the occurrence of different types of metallization in belts in British Columbia as follows:

> There are two main mineral belts in British Columbia separated from each other by an elongated and curved arc of granite batholiths belonging mainly to the early part of the Mesozoic era. This mass includes the Coast Range batholith and the majority of the batholiths occurring in the southern part of British Columbia. The belt which follows along the Pacific coast including the island fringe may be called the Pacific mineral belt; that on the eastern side of the same batholith, the Interior mineral belt. It will be remarked that the two belts differ in the mineralogical composition of their ore-bodies. The ore deposits of the Pacific belt are sought mainly for their copper content; those of the Interior belt are sought mainly for their gold, silver, and lead content. . . .
>
> The reason for the separate occurrence of copper on the one border and of gold, silver, and lead on the other border of the great complex of igneous intrusions is not at once apparent. A fact that may throw some light on the subject is that the copper deposits resemble conditions of high temperature and pressure, even bordering on those of contact deposits, whereas the gold-silver and silver-lead deposits are usually, though not always, associated with fissure veins filled under conditions of a moderate temperature and pressure. . . . Not only is there a contrast between the ore deposits on the two sides of these batholithic masses, but also a contrast in the degree of metamorphism exhibited by the pre-batholithic rocks.

The Wright[8] brothers ascribe the greater metamorphism on the west flank, as compared to the relatively less altered rocks on the east flank, to deeper-seated burial at the time of intrusion of the batholith.

Schofield,[9] on the other hand, thinks that the difference in types of metallization and metamorphism is due, not to deeper burial on the west as compared to the east, but to difference in the slope and relations of the upper surface of the batholith to the present topographic surface. He assumes that, due to relatively less deep erosion, a relatively flat upper surface of the batholith is present at

[7] Schofield, S. J., and Hanson, G., "Geology and Ore Deposits of Salmon River District, B. C.," Canadian Geol. Surv. Mem. 132, pp. 65–66, 1922.

[8] Wright, F. E. and C. W., "The Ketchikan and Wrangell Mining Districts, Alaska," U. S. Geol. Surv. Bull. 347, pp. 65–68, 1908.

[9] Schofield, S. J., and Hansen, G., "Geology and Ore Deposits of Salmon River District, B. C.," Canadian Geol. Surv. Mem. 132, 1922.

or beneath the surface on the west and, due to deeper erosion, a steeply plunging contact on the east. Thus on the east the veins, except a few adjacent to the batholith, would be in a cooler zone at considerable heights above the batholith and would be of intermediate temperature type, whereas those on the west would everywhere be only relatively slightly above the surface of the batholith, and therefore in a hot zone and of the high temperature type.

Schofield's broad generalizations for British Columbia are in part directly applicable, and in part need to be considerably modified, to explain the phenomena in southeastern Alaska. The steepness or flatness, as the case may be, of the slope of the borders of the batholith as they now occur at or near the present topographic surface are not due to differences in depth of erosion on different sides, as postulated by Schofield, but are original, primary, structural variations. For example, along the southwestern portion of the southwest border in Alaska, the general slope of the surface of the batholith is relatively gentle, as indicated by the broad belt of schist and many exposed cupolas and stocks. As the southwest border of the batholith is followed northwest, the width of the belt of metamorphic complex decreases until it practically pinches out northwest of Juneau. This suggests that the slope of the batholith steepens to the northwest until it becomes almost vertical northwest of Juneau. There is no evidence that erosion has cut deeper northwest of Juneau than southeast of it.

The main copper belt in southeastern Alaska is not associated directly with the western border of the batholith, but with a belt (Prince of Wales-Chichagof belt) of outlying stocks that are in general of a more basic composition and average a quartzose diorite. A gold belt intervenes between the copper zone and the main batholith.

A generalized sequence of crystallization is given in Table II. for several types of ore deposits associated with Coast Range intrusives. In the vein deposits, in some cases, the period of crystallization is compressed so that pyrrhotite, sphalerite, and chalcopyrite, or sphalerite, chalcopyrite, and galena, crystallize simultaneously without any noteworthy extension of the period of

crystallization of one mineral beyond another. The periods of crystallization of the minerals, as usual, in general markedly overlap each other, and in some deposits there is a pronounced difference in the ages of two or more of them. The order of crystallization is not invariable, and often two or more are reversed.

TABLE II.

SEQUENCE OF CRYSTALLIZATION.

Magmatic Segregations.	Contact Deposits (Prince of Wales-Chichagof Belt).	High Temperature Replacement Veins Included metamorphic bands in Coast Range Batholith.	Intermediate Temperature Veins (Interior Belt).
1. Ilmenite, Magnetite and Pyrite (sparse)	1. Magnetite, Hematite, Pyrite, and Pyrrhotite	1. Pyrite	1. Pyrite and Arsenopyrite
2. Pyrrhotite, Pentlandite and Chalcopyrite.	2. Chalcopyrite	2. Pyrrhotite, Sphalerite, and Chalcopyrite	2. Pyrrhotite
3. Pentlandite.	3. Sphalerite	3. Chalcopyrite	3. Sphalerite and Chalcopyrite
4. Chalcopyrite.		4. Galena	4. Chalcopyrite
			5. Chalcopyrite, Galena, Tetrahedrite, Silver
			6. Tetrahedrite, Freibergite, Silver and, argentiferous sulphosalts

A noteworthy feature is that in the contact deposits sphalerite is sparse and is, in part at least, later in age than chalcopyrite; whereas in the vein deposits there is often a considerable percentage of sphalerite, and it is earlier than chalcopyrite. This suggests that the reversal in order of separation is the result of primary differences in the concentration of these compounds in the original metalliferous solutions. Attention may also be called to the fact that in the high temperature nickel-copper deposits of the Sudbury, Ontario,[10] district, a little sphalerite is present and is later than the chalcopyrite.

[10] Wandke, Alfred, and Hoffman, Robert, "A Study of the Sudbury Ore Deposits," ECON. GEOL., vol. 19, No. 2, 1924.

The original temperature of the metalliferous solutions given off by the ultrabasic and gabbroic rocks may well have been considerably higher than those from the more siliceous-alkalic facies. Consequently, the time period for the crystallization of the solutions may have been so shortened that some minerals characteristic of intermediate temperature veins would be thrown down within the same vein as the minerals characteristic of the high temperature veins. But is it not possible also that the silver and lead minerals were concentrated to a greater extent within the solutions given off by the siliceous magmas as a result of their longer period of differentiation?

Temperature is usually considered to be one of the dominant agents in controlling the differentiation of metalliferous solutions. There is considerable evidence within each belt in support of this hypothesis. A few examples may be given.

In the dynamically metamorphosed, but relatively slightly recrystallized, belt of rocks in the Juneau and Funter Bay-Hawk Inlet gold belts, and in the slates and dynamically schisted greenstones of the Prince of Wales-Chichagof belt, the quartz veins are commonly milky with some associated carbonates and often mineralized with sparse sulphides or (and) free gold. In the belt of phyllites the quartz veins are predominantly of milky character, with some carbonates, but only occasionally are they metalliferous. In the crystalline schists the quartz veins are usually glassy in nature without sulphides or carbonates and are thin lenticular in character, often forming injection schists.

Tourmaline is sparse to abundant as minute crystals in the phyllites and crystalline schists, but is practically missing from the injection gneisses, pegmatites, and igneous intrusives. Apatite, on the other hand, is more abundant in the crystalline schists and injection gneisses than in the phyllites, and was presumably deposited at a higher temperature.

The copper contact deposits of the Prince of Wales-Chichagof belt were formed probably between temperatures of 500° and 800° C. They carry practically no sphalerite. Copper deposits were also formed in shear zones under intermediate to high tem-

perature conditions, and with them is associated a little sphalerite. This association is probably an effect of the temperature factor.

The arrangement in Table II. is such that each group of minerals to the right was formed in general under conditions of lower temperature. It might therefore be argued that the difference in the kinds of minerals in the successive groups was due to the controlling effect of temperature.

The effects of temperature in controlling the kind of mineral deposition may afford the major part of the explanation for many of the differences in mineralization throughout the region, but it is the intention here to discuss another possible important factor without minimizing the importance of temperature.

The gold quartz veins of the Juneau belt on the west border of the batholith are classified as high temperature veins by Lindgren, though they must be close to the border line of intermediate veins. The gold-silver-lead and base metal veins of the Salmon River district are of intermediate type. The different temperatures at which the two sets of veins formed might be assigned as a major reason for the difference in mineralization, but the writer is inclined to believe that an original difference in the character of the metalliferous solutions is also of importance, and may in part, be correlated with a difference in the type of genetically associated intrusive.

The occurrence of copper contact deposits in the Prince of Wales-Chichagof belt of dioritic rocks, of zinc contact or high temperature replacement deposits in association with the quartz diorite of the western border of the main batholith, and of a sphalerite and galena in contact deposit with the quartz monzonite of the eastern portion of the Coast Range batholith, all in limestone, suggests an appeal to some factor other than temperature to explain such differences.

A contrast may be drawn between the gold quartz veins which occur within the Jualin gabbro-diorite stock in the Juneau district or the Lisianski diorite batholith on Chichagof Island of the Prince of Wales-Chichagof belt, on the one hand, and the gold-silver-lead veins in the Texas granodiorite batholith in the Hyder

district of the Interior belt, on the other hand. In all three cases the veins occur within or near the intrusive bodies and are genetically associated with them. The gold quartz veins consist almost wholly of quartz with a little free gold and a small percentage of sulphides, whereas the gold-silver-lead veins consist of quartz with shoots of heavily mineralized quartz or almost solid sulphide consisting predominantly of galena, and pyrite with a little chalcopyrite, sphalerite, and tetrahedrite, and rare free gold. The gold quartz veins of the diorites are of the high temperature type, and some of the gold-silver-lead veins of the granodiorite also show typical high temperature minerals. The galena veins in the granodiorite might be explained as a later stage mineralization at intermediate temperature. But if so, then it seems peculiar that a similar mineralization should not also have taken place within some of the many diorite stocks of the Prince of Wales-Chichagof belt.

From the southwest to the northeast there are successively (1) the Prince of Wales-Chichagof belt with a predominant metallization of iron, copper and gold in association with dioritic rocks; (2) the Wrangell-Revillagigedo and Juneau belts with a predominant metallization in gold associated with quartz diorite and diorite intrusives; (3) the Coast Range batholith, varying from quartz diorite on the southwest to quartz monzonite on the northeast, with a sparse but predominant metallization of zinc and a little lead, in addition to copper, and iron in the form of pyrite and pyrrhotite; and (4) the Interior or northeast border belt, with a noteworthy metallization of silver-lead in addition to zinc, gold, copper, and iron in association with granodiorite and other intrusives of unknown composition. If we were to arrange the succession of metallization in order of associated increasingly differentiated intrusives, in this region it might run as follows: iron, copper, gold, zinc, silver-lead, the first being associated with diorite and more basic rocks, and the last with granodiorite and more alkalic-siliceous facies. It perhaps needs strong emphasis that one metal does not drop out and the other take its place, but that the metals successively become important in addition to those earlier in the sequence.

The foregoing sequence is based on the average composition of the intrusives and the average kind of mineralization within broad belts. Within each belt, however, there is considerable variation in the composition of the intrusives and in the kinds of mineralization.

From a study of the geology and mineral deposits of the west coast of Vancouver Island, Dolmage[11] and Uglow[12] have concluded that less copper and more iron are found at the contacts with diorite and more copper with granodiorite intrusives. The geology of Vancouver Island appears to correspond most closely to that of the Prince of Wales-Chichagof belt. Granodiorites are present but subordinate to diorite in the latter belt, and it is not known whether this same relation holds here. If it does, then the series of differentiates of small local batholiths is not accompanied by as extended a sequence of mineralization as that which seems to characterize the broader scale differentiation.

Within the Prince of Wales-Chichagof belt and the Juneau gold belt, the feldspar of the predominant volume of intrusives is andesine; but accompanying them, either as local marginal variants or as small stocks or dikes, there is a small volume of albite or albite-oligoclase facies with a very small amount of ferromagnesian minerals. These leucocratic sodic facies include such types as albite diorite, albite monzodiorite, albite granodiorite, albite quartz diorite, and albite trachyte. At the old Treadwell mines on Douglas Island,[13] in the Eagle River Region[14] in the Juneau district, at Funter Bay on Admiralty Island,[15] and on Chichagof Island,[16] dikes of such sodic differentiates are mineralized

[11] Dolmage, Victor, "West Coast of Vancouver Island between Barkley and Quatsino Sounds," Canadian Geol. Surv. Sum. Rept., Pt. *A*, p. 19, 1920.

[12] Uglow, W. L., "Genesis of the Magnetite Deposits near the West Coast of Vancouver Island," ECON. GEOL., vol. 21, p. 355, 1926.

[13] Spencer, A. C., "The Juneau Gold Belt," U. S. Geol. Surv. Bull. 287, p. 92, 1906.

[14] Knopf, Adolph, "The Eagle River Region," U. S. Geol. Surv. Bull. 502, p. 36, 1912.

[15] Mertie, J. B., "Lode Mining in the Juneau and Ketchikan Districts," U. S. Geol. Surv. Bull. 714-B, pp. 114–115, 1921.

[16] Buddington, A. F., "Mineral Investigations in Southeastern Alaska," U. S. Geol. Surv. Bull. 773, pp. 114–124, 1925.

with gold or associated with gold quartz veins. A similar association of gold veins with albitic dikes is reported by Turner[17] and Reid[18] in the "Mother Lode" district of California, and McCann[19] in the Bridge River area, British Columbia.

Emmons[20] has classified mineral deposits with relation to certain conditions of their environment, and in a general way the mineral deposits of the Prince of Wales-Chichagof belt belong between groups 3 and 4, between epibatholithic and embatholithic types; those of the Wrangell-Revillagigedo belt belong between groups 4 and 5, embatholithic to endobatholithic; those of the Coast Range batholith belt between groups 5 and 6, endobatholithic to hypobatholithic; and those of the eastern border or Interior belt, between groups 2 and 3, acrobatholithic to epibatholithic.

Emmons also gives a table showing the relative amounts of certain metals developed as a rule in each of the six groups. The mineral deposits within the belts described in this paper conform in a more or less general way to the appropriate mineralization, as described by Emmons, for the type to which they belong, with the exception of the Coast Range batholith belt. Within the Coast Range batholith (group 5) gold, according to Emmons' table, should predominate; but, so far as the present data go, this is not the case. Emmons, however, states that for endobatholithic deposits "gold deposits greatly predominate, but a few valuable copper deposits and a small number of lead, silver, zinc, and other metals are found." Within each group of deposits, as classified by Emmons according to their environment, the stage and type of differentiation reached by the intrusives must in many cases be quite different within the same or different regions. Certainly this must introduce a factor, tending, even though it

[17] Turner, H. W., "Replacement Deposits in the Sierra Nevada," *Jour. of Geol.*, vol. 7, pp. 389–400.

[18] Reid, J. A., "The East Country of the Mother Lode," *Min. and Sci. Press*, March 2, 1907.

[19] McCann, W. S., "Geology and Mineral Deposits of the Bridge River Map Area, B. C.," Canadian Geol. Surv. Mem. 130, p. 67.

[20] Emmons, W. H., "Relations of Metalliferous Lode Systems to Igneous Intrusives," *Trans. A. I. M. E.*, 1926.

be only in a slight degree, to modify the character of the accompanying mineralization. Such a factor appears to the writer to have been of importance within each belt and between the belts of mineralization in southeastern Alaska, and to necessitate some modification of Emmon's general scheme to be applicable to this region.

Spurr [21] has emphasized, in general, the importance of the stage of differentiation, and gives a mineral sequence for basic, intermediate, and siliceous magma. Rastall [22] similarly emphasizes this factor.

In considering the stage of differentiation, the type of differentiation must also be taken into account; for a biotite quartz monzonite may be formed either by way of intermediate stages such as diorite, quartz diorite, and granodiorite, as usually in the Coast Range; or by way of monzodiorite, augite monzonite, hornblende monzonite, and hornblende quartz monzonite, as in the Adirondacks.

Suggestions of certain possible relations between the kind of mineralization and the composition, and the kind and degree of differentiation of the associated igneous rock of the Coast Range intrusives throughout their range from ultrabasic to alkalic-siliceous types, have been pointed out. The data are too inadequate to put these suggestions forward as more than tentative hypotheses. They do not appear to apply in other regions, and in making such broad generalizations numberless complexities have been passed over. But the subject is certainly one which needs to be discussed by all familiar with the region.

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[21] Spurr, J. E., "The Ore Magmas," 2 (1923), pp. 609–614.
[22] Rastall, R. H., Geology of the metalliferous deposits, pp. 175–180, 1923.

CHANGES IN THE OXIDATION OF IRON IN MAGNETITE.

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INTRODUCTION.

THE writer has recently completed a series of experiments which appear, in part at least, to verify and supplement the conclusions of Welo and Baudisch [1] and of Sosman and Posnjak [2] as to the possibility of changing the condition of oxidation of iron in magnetite (Fe_3O_4) so as to produce a material, called oxidized magnetite, having the composition Fe_2O_3 and yet retaining the magnetic properties and crystal structure of magnetite. The investigation was suggested by Professor A. N. Winchell, and the results attained are due to his helpful advice and constructive criticism.

SUMMARY OF PREVIOUS INVESTIGATIONS.

It will be recalled that the existence of an oxidized magnetite has been known for over sixty years, having first been discovered by Robbins [3] in 1859. Since that time a number of students [4]

[1] Baudisch, O. and Welo, L. A., "The Two-Stage Transformation of Magnetite into Hematite," *Philosophical Mag.*, vol. 50, pp. 399–408, 1925.

[2] Sosman, Robert B. and Posnjak, E., "Ferromagnetic Ferric Oxide, Artificial and Natural," *Jour. Wash. Acad. Sci.*, vol. 15 (14), pp. 329–342, 1925.

[3] Robbins, J., "Magnetic Peroxide of Iron," *Chem. News*, vol. 1, pp. 11–12, 1859.

[4] The following early scientists knew of the existence of a magnetic iron oxide of the composition Fe_2O_3 and prepared it by the action of various oxidizing agents on artificial Fe_3O_4:

Malaguti, F., "Sur le sesquioxyde de fer attirable à l' aimant," *Compt. rend. Acad. Sci. Paris*, vol. 55, pp. 350–352, 1862. Also Ann. Chim. et Phys., (3) vol. 69, pp. 214–224, 1863.

Liversidge, A., "On Iron Rust Possessing Magnetic Properties," Rep. Australasian Assoc. Adv. Sci., pp. 302–320, 1892.

Hilpert, S., "Ueber Beziehungen zwischen chemischen Konstitution und magnetischen Eigenschaften bei Eisenverbindungen," *Ber. Deutsch. Physik. Ges.*, vol. 11, pp. 293–299, 1909. Also *Ber. Deutsch. Chem. Ges.*, vol. 42, pp. 2248–2261, 1909. *Journ. Iron and Steel Inst.*, vol. 82, pp. 65–68, 1910.

independently have rediscovered it, but few of them have made any careful study of its properties or offered any constructive suggestions in explanation of its occurrence.

The more recent investigators, on the other hand, have made definite attempts to ascertain the properties of oxidized magnetite and to arrive at conclusions on the basis of experimental evidence which would account for the phenomena connected with its occurrence.

Sosman and Posnjak [2] began their investigation with the purpose of discovering new methods of preparing the material and observing the relation of its structure and magnetic properties to those of magnetite. They began by precipitating artificial magnetite by the reaction of sodium hydroxide on ferrous sulphate and ferric sulphate solution. Some of this precipitated magnetite was partially oxidized by a solution of NH_4SO_4 and some by air at 105° C. In both cases the resulting oxidized material was found to be deficient in FeO (the latter containing none whatever), but to be highly magnetic, to have a "chocolate brown" color, and to exhibit a structure shown by the X-ray pattern to be in every way identical with that of pure magnetite. It was found to be stable under ordinary conditions, but to invert reversibly to hematite at a little above 500° C. and irreversibly between 500° and 650° C. Their observations as to magnetic susceptibility, stability, color, and structure were in all cases made on the basis of a comparison between unchanged natural magnetite, oxidized precipitated magnetite, and natural oxidized magnetite found in a gossan deposit at Iron Mountain in the Shasta County copper district, California.

Welo and Baudisch [1] went a step further in an attempt to determine temperature relations in the inversions of one oxide to another and structure relations between the three oxides—magnetite, oxidized magnetite, and hematite. They precipitated magnetite in the same manner as Sosman and Posnjak had done, and then heated that material in a stream of oxygen at about 220° C. and thus changed it to oxidized magnetite containing no ferrous iron but identical in magnetic and structural properties with the

original precipitated magnetite. The assumption that its composition was entirely Fe_2O_3 was tested by heating it in the presence of nitrogen to 550° C., at which temperature the structure collapsed and changed to that of hematite with loss of the magnetic properties. The conclusion thus seemed obvious to these authors that the change from magnetite to hematite is purely a temperature effect, provided the ferrous iron in Fe_3O_4 is first oxidized to the ferric form. If it is "not first oxidized, it may be heated in the absence of oxygen to at least 800° C. without permanent loss of permeability." In other words, they conceive the change from magnetite to hematite to be a "two-stage" one, the magnetite first changing to oxidized magnetite at 220° C., at which time the oxidation process is complete and no ferrous iron is present, and then inverting to hematite at about 550° C. It is to be noted that they regard both of these changes as being sudden and occurring at fixed temperatures.

Having proved to their own satisfaction the structural identity of oxidized magnetite with unchanged magnetite, they proceeded on a theoretical basis to suggest possible positions for the extra oxygen atoms which must be present in the structure of the oxidized magnetite. The two positions which they suggest are "the centers of the tetrahedra of trivalent atoms" or "an oxygen atom at the middle of each edge of the unit cube" of magnetite, these being positions which would accommodate the *sizes* of the oxygen atoms to be added.

PRESENT INVESTIGATION AND CONCLUSIONS BASED UPON IT.

The present writer began her investigation in an attempt to obtain experimental evidence which would either prove or disprove the theoretical considerations of Welo and Baudisch as to the correct positions of the additional oxygen atoms in oxidized magnetite. The experimental work was, therefore, very much in the nature of a duplication of that of those writers. Oxidized magnetite was made from three different kinds of magnetite: artificial precipitated magnetite, artificial magnetite made by heating ferrous oxalate (FeC_2O_4) in CO_2 at 550° C. for one-half

hour, and natural magnetite of unknown source. The method was simply that of heating the material to be oxidized in a stream of oxygen at various temperatures and for varied lengths of time, and observing the changes in color, magnetic susceptibility, quantities of ferrous iron present, and structure as revealed by X-ray patterns. With one exception the results obtained are in agreement with those of Welo and Baudisch. Whereas these authors speak of the change from magnetite to oxidized magnetite as occurring suddenly and completely when the temperature of 220° C. is reached, it has been the writer's observation that, on the contrary, the change is a gradual one and is a function not only of the temperature, but also of the length of duration of the process, and that in many cases oxidation may be carried only so far as to form partially oxidized magnetite with a small per cent. of FeO remaining. The experiments seem to show that the oxidation process begins at low temperatures and continues to completion if maintained over a long period of time, but proceeds much more rapidly with increased temperature, providing the temperature is not raised to the point where the structure can no longer maintain itself and suddenly collapses and assumes the structure of hematite, which latter change is believed to be a sudden one, being a structural change and not simply the slow diffusion of new atoms into an already stable structure. It is doubtless not only a temperature effect, but also conditioned by the length of duration of the oxidation process as well as the kind of magnetite. For artificial magnetite it was found that oxidized magnetite could not maintain itself above 500° C., but must invert to hematite at that temperature, whereas the natural magnetite (unless the process were carried on for a very long period of time—*i.e.*, for 8 or 10 hours) was only partially oxidized at that temperature and did not invert to hematite until 800° C. and above was reached.

In all cases, however, it was found that the oxidized magnetite always formed intermediately before the change to hematite, even when the oxidation process was begun at temperatures so high as to be approximately the temperatures of inversion. Further, the

X-ray pattern, whether of partially or completely oxidized magnetite, was in all cases identical both as to relative positions and intensities of the lines of the pattern with that of unchanged magnetite. In other words, the additional oxygen atoms which had entered into the oxidized magnetite structure in no way visibly affected the X-ray pattern and therefore gave no clue to the positions which they occupied within that structure. No doubt, this complete identity of the two patterns explains the fact that Welo and Baudisch found it necessary to base their conclusions as to the positions of the additional atoms on theory, they likewise having found no experimental evidence on which to base them. Although the writer is in agreement with them that the positions to which they would assign the extra oxygen atoms (four in the case of the unit cube) is one which would accommodate the physical *sizes* of the atoms and thus allow them to enter without undue strain on the structure, it is to be noted that there are many other positions in the unit cube which equally well are of sufficient size to permit their entrance.

THEORETICAL CONSIDERATIONS AS TO POSITIONS OF EXTRA OXYGEN ATOMS IN OXIDIZED MAGNETITE.

The writer has constructed from data of Bragg [5] and Wyckoff [6] a small cork model representing eight molecules of Fe_3O_4 (the unit cube), and any number of positions have been found in which there is plenty of room for the small oxygen atoms. It would, therefore, seem probable that some other considerations than mere size should be recognized in the placing of the additional atoms. Inasmuch as the X-ray pattern gives no positive evidence to aid in this, the only alternative is to look for negative evidence which will show where the atoms should *not* be placed.

If one assume that the positions of the four oxygen atoms is, as Welo and Baudisch describe, at the centers of the tetrahedra

[5] Bragg, W. H., "The Structure of the Spinel Group of Crystals," *Philosophical Mag.*, vol. 30 (6), pp. 305–315, Aug., 1915.

[6] Wyckoff, Ralph G., "A Survey of Existing Crystal Structure Data," *Jour. of Franklin Inst.*, vol. 195, pp. 365, 531, 544.

formed by the trivalent iron atoms, it puts two of the oxygen atoms on a plane parallel to the 100 plane of the cube which already has two divalent iron atoms on it. In other words, an atomic weight of 32 is to be added to a plane which already has an atomic weight of 111.7, making a 29 per cent. increase in weight. Inasmuch as the intensity of a given line of the X-ray pattern is a function of the weight of the atoms comprising the plane from which the X-ray is reflected to make that particular line, it would seem that this large increase in the weight of the atoms on the 100 plane should visibly affect the line formed by the ray reflected from that plane and it should appear much more intense in the oxidized magnetite pattern than in that of magnetite. That no such difference is visible throws doubt on Welo and Baudisch's conclusion as to the positions of the extra oxygen atoms.

The alternative arrangement which they suggest is that an oxygen atom be placed at the middle of each edge of the unit cube of magnetite, but again a 29 per cent. increase in atomic weight is added to the plane on which they would place the oxygen atoms, and yet no difference in the intensities of any lines of the X-ray pattern can be noted.

By another line of reasoning it can be shown that the arrangement of atoms which Welo and Baudisch suggest should make a visible difference in the intensity of the lines of the X-ray pattern. The planes on which they would place the extra atoms consist in the original magnetite totally of ferrous iron atoms. The addition of the oxygen atoms to those planes would, therefore, tend to make them more nearly like the Fe_2O_4 planes with which they are interleaved. The result should be that these planes would now reinforce the first order reflection of the X-rays and make a visible difference in the intensities of the lines of the pattern.

If one continue along the lines indicated by this reasoning, he is forced to the conclusion that the extra oxygen atoms have been added in such a way as to avoid their concentration along any planes, so as to make the percentage increase of weight for a given plane much smaller than in the cases cited above with the

result that there is less possibility for a visible variation in intensity. This theory of arrangement of atoms so as to avoid concentration along any particular plane is supported by the fact that there are no changes between the relative positions of the lines of the X-ray pattern of oxidized magnetites and those of ordinary magnetite. Were there offset of some sort or any additional lines present in the oxidized magnetite, it would be inferred that the extra oxygen atoms are concentrated along an entirely new plane different from any existing in ordinary magnetite. It is conceivable, however, that each oxygen atom might occupy a position by itself (*i.e.*, not on any of the established 100 planes of the magnetite crystal nor on a parallel plane containing any of the other three oxygen atoms) and that the weight of this atom standing alone would not be sufficient to visibly affect the X-ray, and so no line would be formed on the pattern. It is also possible that only one oxygen atom might be added to an existing plane consisting of iron atoms only, and thus make no visible difference in the diffraction of the X-rays. In either case the extra oxygen atoms would have to be irregularly spaced and their exact positions indeterminable on the basis of X-ray patterns, simply because their lack of concentration along definite planes would not visibly affect the X-rays.

A recent article by Gruner [7] seems to question whether such oxidized material actually has the magnetite structure (p. 390) and, indeed, takes no account of its being a proper oxidation product of magnetite and formed intermediately in the change from magnetite to hematite. The experiments described in this article for natural magnetites from various localities as they changed to hematite when heated in air at 200° C. with different degrees of amount and speed of oxidation, and the interpretation placed upon them seem to indicate an assumption that in all cases the product formed after oxidizing treatment was either pure hematite or unchanged magnetite. The writer would question whether, if proper means for testing were used, it would not be

[7] Gruner, John W., "Magnetite-Martite-Hematite," ECON. GEOL., vol. 21, pp. 375–393, June–July, 1926.

discovered that much of the material regarded as unchanged magnetite might not be oxidized magnetite. Gruner describes the formation of hematite along the octahedral planes of magnetite with differences in depth of penetration of the oxidation and rate of its occurrence; these differences are attributed to variations in size of grains on the principle that smaller grains, having a greater surface energy than larger ones permit greater diffusion of oxygen atoms in the magnetite space lattice. It is further shown that the formation of the hamitite along the octahedral planes of the magnetite is to be expected if it be assumed that the oxygen atoms which combine with the ferrous iron atoms to change the composition to Fe_2O_3 seek out the octahedral planes of the magnetite crystal, which planes, it is pointed out, have the weakest bonds and give rise to parting or cleavage, and are, therefore, most ready to receive additional oxygen atoms and thereby break down the magnetite space lattice and build up the hematite one.

If one agree with the theory that the additional oxygen atoms in oxidized magnetite are so irregularly spaced as to avoid their concentration along any one plane, it is conceivable that there may be diffusion and irregular movement of these atoms throughout the magnetite structure. Then if such irregular movement were carried far enough (*i.e.*, over a long enough period of time or hastened by a higher temperature) some of the oxygen atoms might find those positions of weakness on the octahedral planes and there break down the structure and form hematite, whereas the other parts of the mineral would still retain the magnetite crystal structure and consist of wholly oxidized magnetite, partially oxidized magnetite, and unchanged magnetite. Such, it is suggested, may have been the condition in Gruner's specimens, and the presence of the oxidized magnetite was simply not observed. This is quite possible, inasmuch as the colors of oxidized magnetite in the finely divided form (the only form in which the writer has observed it) range from dark brown to black, depending upon the degree of oxidation. Furthermore, the fact that the oxidation may have proceeded very slowly with most of the material at any one time only partially oxidized would be a factor tending to obscure the presence of oxidized magnetite.

CONCLUSIONS.

It has been definitely ascertained by the studies of Welo and Baudisch and by the writer's experiments that natural and artificial magnetite may be oxidized to oxidized magnetite, and the studies of Sosman and Posnjak show that oxidized magnetite also occurs in nature. It is believed to be an intermediate material formed in the change from magnetite to hematite and formed wherever magnetite is in the presence of oxidizing agents, the rate of its formation being dependent upon the temperature at which, and the length of time during which, the oxidation process is carried on, and its stability dependent upon the same factors, which vary for different kinds of magnetite. The fact that the X-ray pattern of oxidized magnetite is identical with that of unchanged magnetite suggests that the oxygen atoms which are added when oxidized magnetite is formed are irregularly spaced within the magnetite crystal structure and their actual positions cannot be definitely determined. In further studies it is important that the fact of the formation of oxidized magnetite in changes from magnetite to hematite be taken into consideration.

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EDITORIAL

HOT SPRINGS AND MAGMATIC EMANATIONS.

LITTLE of a general nature is found in the pages of this journal on the relation of hot springs and emanations from magmas and yet it is a subject of compelling interest for the economic geologist for rightly or wrongly we connect the two phenomena with genesis of ore deposits. Elsewhere, considerable discussion has taken place; I refer, for instance, to the instructive symposium by many eminent men in *Journal of Geology* for 1924; likewise to the notable investigations by the men of the Geophysical Laboratory of Washington in the Valley of a Thousand Smokes and at Lassen Peak.

In this discussion the consensus of opinion was adverse to the idea that even the hottest springs carry large quantities or predominating quantities of magmatic water. The tendency seemed to be that they are chiefly of meteoric origin, heated by the proximity of igneous bodies and by mixtures of hot magmatic gases. Of course, this is no new idea; French geologists from Daubree to DeLaunay have held this for many years. And the geophysicists, in the discussion referred to, rallied definitely about this conception. Substantially this is the argument of Day, Allen and Morey. It applies to Katmai, Alaska, to the Yellowstone, to Iceland, to New Zealand.

Now, to begin with, I shall gladly admit that Dr. E. T. Allen has interpreted correctly the problem of the hot springs on the flank of Lassen Peak—a nearly extinct volcano. His arguments are cogent and convincing. The springs are mainly of meteoric origin and they have been heated by abundant gaseous emissions or lava plug, buried not too deeply. The emissions consisted of water gas, carbon dioxide, some sulphur compound, etc. In the scant deposits he found pyrite, thiosulphates, alunite and few

other things. Evidently there is no sinter or tufa. The waters are neutral or acid with much of the sulphate radicle. Dissolved constituents are derived from decomposition of the rocks by probably acid gases, carried by surface waters.

But now come Day and Allen saying that a similar origin is to be assumed for all hot springs in igneous regions. Deeply buried batholiths squirt out gases of many kinds, water no doubt predominating. These gases ascend propelled by vapor tension and chased by continuing gas pressure from below until they reach meteoric waters which actuated by hydrostatic pressure, greedily soak up these vapors and carry them to the surface, attacking the rocks as they go. As there are many constituents carried along with the magmatic water gas the vapor tension of the latter is so lowered that I quote the words of Day and Allen:[1]

> As the temperature falls, the process continues. Not until it reaches the critical temperature—strongly modified as it is by the soluble matter in the magma—would it be possible for the water to condense, and not then unless the pressure were sufficiently great. The experimental studies of G. W. Morey indicate, however, that the vapor pressure of water in the magma would be so reduced by the soluble matter that a pressure sufficient to condense the water would serve only to drive the water vapor into the magma. In other words, if water is to leave the magma at all it must do so as steam. If one is inclined to argue that some important factor has been omitted from the discussion, invalidating our conclusion, he finds himself confronted by the necessary of explaining how liquid water is raised to the surface. A force adequate to do this has so far not been suggested. . . . We are led therefore to the conception that magmatic water, in so far as it is present in hot springs, rises from the magma along with the other gases as steam, is condensed somewhere near the surface of the ground by meteoric water with which it becomes mingled, and that the mineral burden which the springs contain, except for the volatile constituents, comes from a depth no greater than the ground water penetrates.

In other words, the magmatic effluvia, if condensed to a liquid have no ascending power. They must ascend as gases or not at all. This somewhat startling conclusion is largely based on certain experiments by Dr. Morey, stated in his brief but very pregnant discussion in *Journal of Geology* of 1924. Now this is as-

[1] *Journal of Geology*, 32, 1924, pp. 185–186.

suredly disconcerting to many of us who have gaily talked of vast bodies of ascending magmatic liquids. Also I should say to Dr. Niggli, who has so convincingly set forth by T. P. diagrams how the "pneumatolytic" stage is followed by the hydrothermal stage which sends the liquids on their upward journey.

Quite incidentally Dr. Morey assures us of another thing of which I have long had certain suspicions, namely that there is no such things as pneumatolytic deposition, in the sense of deposition by agencies above their critical temperature. He says the dissolved substances raise the critical temperature of water and similar liquids so high that the fluids can never have reached the critical point.

All very well, but I would like to say, that there are hot springs *and* hot springs. What Dr. Allen has described I would call the volcanic type, which have their origin near the surface and are caused by gaseous emanations from near surface magmas. The hot springs which the economic geologist has connected with ore deposits are of a quite different type: Always alkaline, carrying but little sulphates but mostly sodium carbonate, sodium chloride and silica. These are the agencies which in a few places, as at Steamboat Springs, Nevada, almost produce an ore deposit before our eyes. These springs owe their emanations to deepseated magmas usually, I am sure, thousands of feet below the surface and far below the zone of actively circulating surface waters. Assuming that the emanations were given off in gaseous form how could they rise through cooling rocks to reach the carrying meteoric waters without being condensed. Once condensed, according to Day, they were minus their ascending power and had to stay where they were.

Of course, there is still another aspect to this problem. The geophysicists apparently hold that everything that escapes from the crystallizing magma is in gaseous form. In this they, of course, overlook the very important point that in ore deposits there are vast quantities of non-volatile material. I refer particularly to silica but also to other things like iron and magnesium, all of which can hardly have been emitted in gaseous form—as chlorides, fluorides, etc. The silica surely comes from the magma

and the chances are it did not ascend in gaseous form. All this, you realize, took place far below the zone of surface waters. I conclude that in spite of what the geophysicists say the magmatic emanations ascended in liquid form.

Here is where Mr. J. E. Spurr comes in: He says that they were in liquid form and were in fact a viscous "ore magma," propelled by "telluric force." I presume like any ordinary dike. That this "ore magma" was indeed in substance an aqueous solution is a conclusion which seems difficult to escape and in spite of many statements to the contrary Mr. Spurr seems likely to be forced to admit this.

The main question then seems to be, and here I am afraid we shall have to refer the question back to the geophysicists: Wanted, a propelling force sufficient to raise a liquid emanation from the top of a batholith to the surface. Perhaps some one will elucidate this question?

WALDEMAR LINDGREN.

DISCUSSION AND INFORMAL COMMUNICATIONS

PREPARATION OF POLISHED SECTIONS OF ORES.

Sir: The paper by M. N. Short under the above title in ECONOMIC GEOLOGY for November, 1926, has given a very complete outline of polishing methods. Details are given for the first time of many invaluable methods, useful especially in research. It seemed to the writer, however, that the system recommended is rather complicated for the class room and for the investigator with limited facilities. To encourage those who may not be able to have an elaborate system, the following notes are presented.

The system in use in the laboratory of the Department of Geology of the University of Minnesota has given very satisfactory results in polishing the several thousand specimens now in the mineralographic collection. With reasonable care the polish proves satisfactory for magnifications up to 700 times.[1]

The system has the advantage of being economical from the standpoint of both materials and equipment and the preparation of material is rapid. The writer timed the procedure for polishing two typical specimens from breaking the chip to examination under the microscope. A titaniferous magnetite specimen representing a hard surface, required seven minutes and a chalcocite-bornite-quartz specimen from Butte, representing a relatively soft surface, required six minutes. Ten minutes would probably be a fair estimate for specimens presenting no unusual difficulties. The system was designed by Dr. T. M. Broderick in 1919–1920,

[1] See micrographs in the following articles.
ECON. GEOL., vol. 18, pp. 270–277, 1923.
Eng. and Min. Jour.-Press, vol. 116, pp. 237–238 and 409–412, 1923.
American Mineralogist, vol. 8, pp. 162–165, 1923.
Eng. and Min. Jour.-Press, vol. 118, pp. 735–738, 1924.
ECON. GEOL., vol. 20, pp. 261–265, 1925.
Eng. and Min. Jour.-Press, vol. 112, pp. 375–377, 1926.

and has been somewhat modified in practice by the writer since that time.

Small specimens, preferably not over one inch in diameter, as recommended by Dr. Short, are ground on a horizontal plate on an old style thin-section machine, using a paste of 46 or 120 alundum. The abrasive used at this stage seems unimportant providing it cuts fast enough. The flat surface thus obtained is beveled on a carborundum stone or on a carborundum wheel. The next step is grinding by hand on a glass plate with alundum 5f, followed on another plate with alundum 60f. About one minute usually suffices for this step, but in some cases more time can be spent to advantage. It would perhaps be more convenient to have these glass plates mounted on a horizontal disc.

The preceding steps are grinding and those following are polishing. For polishing a Norton and Company machine, fitted with two vertical steel wheels with brass bands, is used. This is driven at 1,800 R. P. M. Three of the faces are mounted with heavy linen or sheeting. The best grade of sheeting gives very satisfactory results and costs much less than linen. All abrasives are applied to these wheels with paint brushes dipped in the abrasive suspended in water. Alundum 60f is used on the first wheel, chromic oxide (10 minute) on the second, and either rouge (60 minute) or Shamva metallographic polishing powder (Goldwynne and Co., 26 Cortlandt Street, New York), for the final polish. The Shamva powder gives excellent results if kept securely covered in moisture proof cans and mixed only as used. It is magnesia and cakes on exposure to air or water. This is objectionable and consequently the magnetic rouge method described by Dr. Short should be more easily manipulated.

It is, of course, necessary to wash the specimen and hands carefully between each procedure and use considerable caution to prevent contamination of the materials.

No permanent mount is used such as that described by Dr. Short. This is rather expensive except for permanent collections such as that of the Geological Survey; furthermore it is desirable for student work to have the specimen free for mega-

scopic examination and blowpipe tests. For mounting sections a screw cup patterned after that shown by Davy and Farnum, but made of much heavier material, is used with a heavy glass slide (1/8 inch thick) with plasticine. This gives a rapid mount and the specimens occupy little space when unmounted.

Specimens are card indexed by serial number as received and each fragment has an India ink number on a base of white enamel. This is coated with shellac to make it more permanent.

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MAGNESITE DEPOSITS OF MANCHURIA.

Sir: Replying to Mr. Nishihara's criticisms of my views on the origin of the Manchuria magnesite [1] I wish to call attention to a paragraph in my original article,[2] in which I noted that there is "some similarity between the different important deposits of crystalline magnesite with respect to their mode of occurrence . . ." and ". . . while in the case of the Quebec, Austrian and Washington deposits the geologists who have investigated them seem to think that the evidence for some one mode of origin is quite conclusive, it may be questioned whether in the case of the Manchurian deposits the proof is sufficient to establish with certainty any one of several possible hypotheses."

I therefore repeat that with the evidence at hand any theory must be open to revision, although the one I suggested seems to be supported to a reasonable degree by the facts.

I cannot agree with him that we have no right to assume the existence of a mass of granite or other intrusive rock at depth which might have supplied magnesia in magmatic waters. My original discussion did not indicate that the granite 15 km. northeast supplied the magnesian solution, but that the fact of granite outcropping in three areas around the magnesite, lends color to the theory that it might underlie the region at depth.

[1] ECON. GEOL., Vol. 21, p. 190, 1926.
[2] ECON. GEOL., Vol. 20, p. 48, 1925.

The main problem is that of the source of such an enormous quantity of magnesia as the deposits contain. One could assume of course that this great volume of magnesia was of sedimentary origin, but if so its source is hard to understand, and also its combination preceding deposition.

I also find it difficult to conceive that such a large volume of magnesian salts should be precipitated in such a restricted area and during such a restricted period of time. The question of the source of such large quantities of magnesite is I admit not easily solved. If the magmatic origin of the magnesia is questionable it seems to me that the theory of chemical precipitation is still more so, especially when we consider the geologic age, and structural relations of the deposits. One may ask how is the simple chemical precipitation theory of Nishihara going to explain the frequent curious relation of the magnesite to the beds of slate or schist.

While Mr. Nishihara claims that the gradation of magnesite to dolomite is no evidence of replacement, he nevertheless remarks that it would be interesting to have analyses showing this, although he claims that the contact between dolomite and magnesite is distinct.

The following five analyses (*A–F*) taken from a magnesite band near the southeastern foot of Niu-hsin-shan, show such changes from the one carbonate to the other.

Analyses *F* and *G* have been made from the specimens taken from immediately upper and lower sides of the magnesite band, that is, from dolomite.

(1)

	A	*B*	*C*	*D*	*E*	*F*	*G*
SiO_2	2.78	1.31	2.73	0.68	1.56	1.18	6.41
Al_2O_3	1.04	0.47	0.87	0.19	0.38	0.18	0.32
Fe_2O_3	0.68	1.17	0.79	1.01	2.18	1.33	1.63
CaO	29.66	2.53	1.23	0.30	29.51	30.36	27.06
MgO	18.80	43.52	44.39	45.78	20.55	20.89	19.55
Co_2	44.54	50.95	50.23	51.13	45.31	44.84	44.59
Ignit. loss	1.31	—	—	0.11	—	1.08	—
Total	98.81	99.95	100.24	99.20	99.49	99.86	99.56
$MgCO_3$	—	91.39	93.22	96.14	—	—	—
Sp. gr.	2.86	2.93	2.96	3.01	2.86	2.86	2.87

(2)						(3)			
	H	*I*	*J*	*K*	*L*	*M*	*N*	*O*	*P*
SiO_2	2.37	2.59	1.60	0.84	0.67	0.58	0.62	0.51	2.47
Al_2O_3	0.39	0.65	0.26	0.08	0.08	0.06	0.08	0.19	0.14
Fe_2O_3	1.02	2.47	0.67	0.74	0.85	0.56	0.88	1.29	1.61
CaO	2.11	2.17	9.55	15.09	27.73	0.76	7.23	24.01	24.75
MgO	43.42	41.88	37.97	31.69	21.00	45.49	40.90	23.12	20.86
CO_2	45.57	49.68	48.64	51.39	48.50	—	—	—	—
Ignit. loss	4.41	—	—	—	0.36	51.01	50.28	50.17	48.70
Total	99.29	99.44	98.69	99.83	99.19	98.46	99.99	99.29	98.53

Tables (2) and (3) typically show a gradation from magnesite to dolomite in their chemical compositions right across their beds within distances 60 and 9 meters respectively at different parts in the same locality of Niu-hsin-shan. In my original article reference is made to over 200 chemical analyses which show gradation from magnesite to dolomite in the Kuan-ma-shan deposits.

Still later additional evidence has been furnished by M. A. Mita of the An-shan Iron and Steel Works, who made 148 analyses from the hill of Niu-hsin-shan. These clearly show gradational changes from magnesite to dolomite.

It may be admitted that attempts to show the gradation from magnesite to dolomite by optical methods are difficult, but the reaction of dolomite to cold concentrated hydrochloric acid, as seen under the microscope, is quite characteristic.

A new method to distinguish between magnesite and dolomite which the writer has published, has served as a means of establishing the existence of gradations.

I see no serious objection to what Nishihara refers to as selective action of the magnesian solution on certain beds. It is a well known fact that in replacement of limestone, by other minerals, one bed may be replaced while another remains unaffected. This has been noted for instance in the replacement of limestone by garnet and also in dolomitization. In fact it is less difficult to comprehend this, than to explain how such a large volume of magnesia could be precipitated so locally from a sea which was spread over a much larger area than the magnesite deposits are known to be. At the northeastern part of the district there are

beds of the same age as those containing the magnesite, which are free from that mineral. In other words the ancient Manchurian sea is shown to have extended over a large area, whereas the magnesite is in limited amounts, and not widespread as one would expect it to be, if, of sedimentary origin. Nor is it confined to a single horizon.

A distinct stylolitic structure which the writer recently has discovered in the Manchurian magnesite is occasionally recognizable, which is called by him "black lines." [3] They are nothing but a remnant of intense metamorphism, mostly of katamorphic [4] nature although the metasomatic replacement from limestone by magnesite itself represents an anamorphic change. The volume of magnesite deposits may have undergone a reduction as indicated by the stylolites structure in limestones and marbles of Indiana,[5] Tennessee [6] and of Germany.[7] Theoretically, according to Van Hise,[8] 12 per cent. of the volume may be reduced when calcite is converted into magnesite, therefore, the Manchurian deposits might have decreased at least several per cent. in volume in changing from limestone to magnesite. This the writer believes, is indicated by their stylolitic structure or "black lines." This also indicates indirectly that the magnesite beds are of secondary character and are not an original sediment.

The general absence of bedded structure in the magnesite may be due to regional metamorphism, while the black lines in the magnesite are the metamorphosed remnants of carbonaceous clay material.

[3] Niinomy, K., "On the Black Lines in the Manchurian Magnesite," *Jour. Soc. Iron and Steel*, An-shan, Manchuria; No. 16, Oct., 1925, pp. 538–546 (in Japanese).

[4] Van Hise, C. R., "A Treatise on Metamorphism," Mon. XLVII., U. S. Geol. Survey, 1904, pp. 159 et seq.

[5] Gordon, C. H., "On the Nature and Origin of the Stylolitic Structure in Tennessee Marble," *Jour. Geol.*, Vol. XXVI., 1918, pp. 561–568.

[6] Stockdale, P. B., "Stylolites: Their Nature and Origin," *Indiana Univ. Studies*, Vol. IX., No. 55, Dec., 1922.

Stockdale, P. B., "The Stratigraphic Significance of Solution in Rocks," *Jour. Geol.*, Vol. XXXIV., 1926, pp. 399–414.

[7] Wagner, G., "Stylolithen und Drucksuturen," *Geol. u. paleont. Abhandlungen*, N. F., Vol. XI. (XV.), Heft 2, 1, 1923, pp. 101–127.

[8] Van Hise, C. R., "A Treatise on Metamorphism," *op. cit.*, pp. 379–380

In spite of Mr. Nishihara's apparently serious objection to the replacement idea, he seems to forget that such an origin is by no means new, and has been quite generally accepted for several other similar regions, in other parts of the world. It is possible that Mr. Nishihara's views, which appear to be based on the study of one deposit [9] might be altered after a study of the whole region in which these magnesite bodies occur.

K. NIINOMY.

DAIREN, MANCHURIA.

[9] Nishihara, H., "An Enormous Magnesite Deposit in Manchuria," *Eng. and Min. Jour. Press,* CXIX., pp. 488–489, 1925.

REVIEWS

Ore Deposits of the Jerome and Bradshaw Mountains Quadrangles, Arizona. By WALDEMAR LINDGREN, with statistical notes by V. C. HEIKES. U. S. Geological Survey Bull. 782, 1926. Pp. 192, 10 text figures, 23 plates, including geologic maps of the two quadrangles.

To the average geologist and mining engineer the title of this bulletin will suggest little more than Jerome and the two mines, the United Verde and the United Verde Extension (U. V. X.). It describes, however, a large mineralized area that includes a wide variety of ore deposits, and consequently contains much of interest to the economic geologist outside of the Jerome district. As indicated by the title, the bulletin deals primarly with the ore deposits of the two quadrangles. The general geology of the area is described briefly in seventeen pages. Thirty pages are devoted to a general description of the ore deposits. One hundred and thirty-three pages are given to a detailed description of the various districts and their mines. The two quadrangles include 19 mining districts, and the locations of 166 mines are given on the two maps, 33 in the Jerome Quadrangle and 133 in the Bradshaw Mountains Quadrangle. The whole production of gold, silver, copper, lead, and zinc to the end of 1923 is estimated at about $300,000,000. In order of value, copper ranks first; the value of gold is slightly in excess of that of silver; lead and zinc were produced in but small quantity. The Bradshaw Mountains Quadrangle produced about $18,000,000 in gold and silver. The United Verde has produced considerably over one half of the total value, and the U. V. X. about one fourth of the total. Both mines have been remarkable dividened payers, the United Verde has averaged over $2,000,000 annually since 1900, and the U. V. X has maintained the same average in the decade of its productive history.

The geologic maps of the report are based on the Bradshaw Mountains Folio of the U. S. Geological Survey which was surveyed by Jaggar and Palache in 1901 and a manuscript map of the Jerome Quadrangle prepared by Jenkins, Wilson, and Reber for the Arizona Bureau of Mines. The pre-Cambrian Yavapai schist and Bradshaw granite outcrop over most of the Bradshaw Mountains Quadrangle and much of the southern half of the Jerome Quadrangle. Intruded in them are smaller areas of diorite, granodiorite, and monzonite porphyry, and dikes of rhyolite

porphyry. The diorite and monzonite porphyry are considered facies of the Bradshaw granite or closely allied intrusives. The granodiorite is probably of Cretaceous or early Tertiary age. Younger than the granodiorite are abundant dikes of rhyolite porphyry in the western part of the Bradshaw Mountains Quadrangle. In the northern part of the Jerome Quadrangle are large areas of almost horizontal Paleozoic beds that are of interest only because near their southern limit they overlie the U. V. X. orebody and fix the older age of the Jerome copper deposits. In both quadrangles are large areas of Tertiary volcanics. In the Verde Valley, east of Jerome, is a considerable thickness of white lake beds that Lindgren regards of Pliocene age but classified by Reber and more recently by J. L. Fearing, Jr., as Quaternary. All of the rocks except the pre-Cambrian are practically barren of ore deposits.

The following types of ore deposits occur in the district:

Pre-Cambrian deposits.
- Pyritic copper deposits in schist.
- Magnetite deposits.
- Contact metamorphic deposits.
- Gold-quartz veins.
- Gold-quartz tourmaline replacement deposits.
- Quartz veins carrying silver, copper, and lead.

Later gold and silver veins (Mesozoic? or early Tertiary?).
- Quartz veins carrying gold and silver.
- Silver veins.
  - Veins with barite gangue.
  - Veins with quartz gangue.

The pyritic copper deposits in schist have yielded more metal than all the other types combined. They include the United Verde, U. V. X., and several other of the more important mines of the area. They are replacements of the Yavapai schist; and the replaced rocks may be rhyolite schist, greenstone schist, biotite schist, or chlorite schist. In many places the ores have inherited the schistose structure, but no schistosity has been superimposed upon them. The paragenetic sequence is quartz and carbonates, a little arsenopyrite, much pyrite, fracturing and shattering, a little magnetite and specularite, sphalerite, chalcopyrite, a little tennantite and galena. Most of the mines have yielded ore carrying 3–5 per cent. copper, but some of the ores contain as much as 10 per cent. Cu. The type is not as directly connected with the Bradshaw granite as some of the pre-Cambrian veins, but the mineralizing solutions are thought to have come from deeper levels of the granitic magma.

The magnetite deposits are not of economic importance. They occur in the schists with a gangue of quartz and silicates. Some are banded

with red jasper similar to the Lake Superior iron formations and seem to be of sedimentary origin. In other cases the Yavapai schist seems to have been more or less penetrated by granitic emanations that introduced magnetite. Scattered tourmaline in the schist is believed to have had this origin. At a few mines iron and copper sulphides are associated with magnetite, epidote, garnet, actinolite, etc., and residual calcite, an assemblage that suggests contact metamorphism of calcareous schist and thin limestone lenses by the granitic emanations. This type is of minor importance.

More widespread and numerous are the gold-quartz veins. They are veins of massive quartz without druses with a little carbonate and tourmaline. The common sulphides occur scantily; gold is free in bunches and pockets or is finely disseminated in sulphides. The ores generally average below $20 a ton and the shoots are small and irregular, so that they have not yielded more than one million dollars. The disintegration of the veins doubtless furnished much of the gold of the placers. The common occurrence of tourmaline in the schists and in pegmatites near the contact of the Bradshaw granite and in the veins, and the deep-seated character of the veins are interpreted to point to the genetic connection of the veins with the Bradshaw granite but with the reservation: "The pegmatites, however, form a distinct and separate unit, and no transitions between pegmatites and gold quartz veins have been found." The Iron King mine in the Bigbug district is a replacement in schist by the same granitic emanations that elsewhere formed the gold-quartz-tourmaline veins. The last group of pre-Cambrian deposits includes several quartz veins with unusual filling of silver, copper, and lead minerals. The Yaeger mine between Jerome and Prescott with an output of over one million dollars from high grade bornite ore produced more than any other mine outside of the pyritic-copper replacement group.

All of the pre-Cambrian deposits with the exception of the pyritic copper are believed to have been formed by emanations from the Bradshaw granite, and the latter type is thought to be genetically related to the same granitic magma.

The later gold and silver veins are divided into three groups on the basis of their filling, but are considered as a single genetic unit. They are essentially quartz veins carrying chiefly gold or silver, or both, and subordinate amounts of the common sulphides. Visible gold occurs in the oxidized zone, but in the primary ore the gold is microscopically intergrown with the sulphides. The silver occurs as argentite in galena, tetrahedrite, ruby silver, and in the zone of oxidation as native and horn silver. The quartz is mainly of milky color and drusy and grades into well-defined comb structure. High temperature minerals are almost lacking, and the wallrock is sericitized and carbonatized. Structure and

mineral composition point to their deposition in the intermediate zone. They are confined to the western part of the Bradshaw Mountains Quadrangle and are genetically related to the remarkable system of rhyolite porphyry dikes of that area. The total production of these veins is estimated at close to $20,000,000.

Interesting relations are set forth between water level, oxidation, and secondary enrichment. The water level is irregular and rather deep and the supply scant, so that the boundary between oxidized and primary ore is indefinite. Residual sulphides are found close to the surface and oxidation penetrates below water level. Gold and more pronouncedly silver show marked enrichment in the oxidized ores, but no supergene sulphide zone has been developed since pre-Cambrian time. The phenomenal chalcocite ore body of the U. V. X. mine is a pre-Cambrian enrichment that has been preserved beneath a Paleozoic covering. This chalcocite zone has a depth of 400 to 600 feet and extended to a depth of at least 800 feet below the pre-Cambrian peneplain. In discussing the persistence of the ores in depth attention is called to the great vertical extent of the gigantic pipe-like ore-shoot of the United Verde mine. The bottom has not been reached at a depth of 2,500 feet, so that its total original length was over 4,000 feet. Within the portion now known there is no filling of open space but simply a replacement by ore, effected by solutions rising through and penetrating this pipe. Concerning these solutions is added: "Nothing but solutions, perhaps concentrated but assuredly very mobile, subject to diffusion and osmotic action, could have formed this deposit. To talk about an 'ore magma' in such a case is to play with words."

One can hardly resist the temptation to review the descriptions of the United Verde and the U. V. X mines. They had been previously described by Reber and others, and since the appearance of this bulletin again by Fearing, but Lindgren has added much by more precise and accurate description of the replacement processes and the paragenetic relations of the minerals. The geologists who followed the discussion of the genesis of the Rio Tinto deposits in Spain last summer will find much of interest in the description of this cylindrical ore mass with a diameter of about 700 feet which is mainly a replacement of quartz porphyry and concerning which it can be said that there is "no other single primary pyritic mass of ore which equals it in size and richness." Just as remarkable is the story of the U. V. X. mine. After fourteen years of persistent prospecting through a covering of Tertiary volcanics and Paleozoic sediments, a pre-Cambrian supergene chalcocite zone was discovered of such phenomenal richness that in nine years dividends of over $18,000,000 were paid. The history of the U. V. X. mine, which has been told in considerable fullness by T. A. Rickard, is one of the outstanding

romances of mining. Lingren closes his description of the mine with a poetic account of the geologic history of the deposit which he concludes with these words: "Intelligence needed metals. Intelligence found the bonanza." Surely the laurels ought to be shared with the perseverance that is born of the supreme optimism of the mining man!

The bulletin contains a wealth of information concerning a mineralized area which maintains a first rank position because of the production of two contiguous mines but which otherwise is characterized by the paralyzation of a large number of small mines and prospects. It presents an account of the rocks and their metasomatic alterations and the paragenesis and genesis of the ores with a degree of thoroughness and accuracy that can be achieved only by one who has the skill and experience possessed by its author in the application of the microscope to those problems. In assembling such a mass of material as the bulletin contains, a few oversights are bound to creep in. That a few place names in the text have not been recorded on the maps is found out by the reader only after a futile search. There is some discrepency or inconsistency in the production totals given in different places in the bulletin. The geologic map on page 67 does not have its orientation designated, and the orientation is not what the position of the caption would indicate. These are but minor matters that do not impair the general excellence and usefulness of the bulletin.

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Supplement to an Introduction to Sedimentary Petrography. By H. B. MILNER. Pp. 156. Plates 12, Fig. 4, Cro. 8vo. Thos. Murby and Co., London. Price 9 s. 6 d.

A second volume of this useful little manual is welcome. It should be added to the working library of all petroleum technologists, or others engaged in the study of sediments.

About one third of the supplement is devoted to the description of twenty additional mineral species. This makes a total of 74 species described in the two volumes. The same scheme of description is used as in the early volume, except an additional heading covering occurrence. The occurrences cited are, for the most part, English. The same high quality of photography employed in the earlier volume has been maintained in the figuring of twenty-eight species.

The new volume contains the same number of chapters as the earlier volume, and the subject matter of the first, second, and fourth chapters may be considered as additions to the three original chapters. The third chapter of the first volume dealt briefly with "the principles and practices

of correlation of sediments by petrographic methods," whereas the third chapter of the supplement cites 12 examples of this procedure. Seven of these illustrations are oil-sand differentiations and the remaining five are surface outcrop correlations.

The lack of reference to index of refraction criteria for mineral determination was a source of criticism in the first volume (see this journal, Vol. 18, 1923, p. 198). This has been remedied in the supplement. Nine tables for the determination of minerals on the basis of optical properties are included.

For one already acquainted with petrographic methods in general this small volume has much to recommend it. It is to be hoped that the future revisions, promised by the author, will contain more specific data upon the treatment of clays and shales, especially on the methods for their deflocculation.

A selected bibliography of 114 entries of articles published since the release of the first volume in 1922, concludes the supplement.

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Metallographic Researches. By Carl Benedicks. Pp. 307, 153 text figures. McGraw-Hill Book Co., New York, 1926. Price $4.00.

As the preface states, this book is the publication of a series of lectures delivered in the United States in 1925 by Carl Benedicks, former professor of physics at the University of Stockholm and director of the Metallografiska Institutet, Stockholm, Sweden. Although it deals, primarily, with miscellaneous metallurgical subjects, it contains also material of interest to geologists. In the first two chapters the author treats of the properties of metals and arrives at the conclusion that the fundamental structure is, instead of a rigid atomic lattice, a "dynamic lattice" which allows the atoms to vibrate about a mean position so they have a free path shorter than but comparable to the path of a molecule in a gas. He develops the "phoretic electron theory" from the dynamic lattice and explains by it many thermal and electrical conductivity phenomena. The cause of hardness in metals and alloys is treated in the third chapter. In Chapter 4 there is a discussion of some of the properties of meteoric iron and a description of the production of artificial "Widmanstätten structure" and of cubic "meteoric" iron. The fifth chapter deals with improvements of photomicrography with high magnification. Theory of suspension of the camera to eliminate vibration is demonstrated by the description of an application to the optical bench type. For illumination a thin plane glass illuminator is found best because thicker glass causes diffusion and so increases the exposure. The effect of diaphragm width

and of sector illumination is discussed. In chapter six a microchemical method for detecting small concentrations of one element in a heterogeneous mixture is given. It consists in coating the surface with gelatin, then allowing some solvent to act on the surface through the gelatin, then the application of a reagent that causes a precipitation of the element to be detected. The precipitate being held in the gelatin, its locus indicates the point from which the element was derived. The method seems, to the reviewer, susceptible of being used to determine microscopic particles of opaque minerals in ore mixtures where ordinary microchemical tests are not conclusive. The last five chapters are mainly metallurgical dealing with the critical points of steel, the obtaining of sharp thermal curves, the specific gravity of molten metal, a rational ingot section for hard rolled material, and the influence of hot walls on boiler corrosion and segregation of hot metals. In the last chapter he points out the difference obtained in the Ludwig-Soret principle in the horizontal and vertical position and suggests the importance of the principle in the differentiation of magmas. The book displays the usual excellent McGraw-Hill workmanship and the illustrations are well reproduced. It is a book that an economic geologist would find suggestive and helpful.

FRELEIGH F. OSBORNE.

Handbook for Prospectors. By M. W. VON BERNEWITZ. 319 pp. McGraw-Hill Book Co., New York, 1926. Price $3.00.

This convenient little leather-bound handbook gives information designed primarily for the prospector but also valuable to the young field geologist and mining engineer. There are three parts. Part I. devotes 22 pages to outfits, modes of transportation, and mining laws. Part II., 73 pages, deals with mineralogy, elementary general geology, occurrence of ores, alteration, outcrops, sampling and field tests of minerals. The last 20 pages tells about mining methods applied to prospects. Part III., 170 pages, treats of the metallic and non-metallic minerals, their properties, occurrence, tests and where to look for them. A thirty-page glossary at the end adds value.

The book presents in simple language and compact form much valuable information. It tells how to tie a pack-horse hitch and how to test for vanadium; how to market ores, and where to look for certain minerals. The geology is sketchy, as presumably it is meant to be, but good diagrams clarify it, although a picture of a gold pan hardly seems necessary. The make-up of the book is a credit to the fine craftsmanship of the McGraw-Hill Book Company.

ALAN BATEMAN.

Stories in Stone. By WILLIS T. LEE. Library of Modern Sciences. Pp. 226. D. Van Nostrand Co., 1926. Price, $3.00.

Another of the Modern Science series under the general editorship of Edwin E. Slosson tells a story of geology and of the geologist couched in terms readily understood by everyone. It is meant primarily for the lay reader, but geologists themselves will enjoy and appreciate it. Under "Landscapes Old and New," in Chapter 3, the story of the Grand Canyon is told, and under such headings as "Ancient Landscapes," "Jurassic Scenes," or "Tertiary Landscapes," the earlier conditions of the earth and the rise of animals, or the natural scenery of our great West and the life of dinosaurs, or mammals and their evolution, is told in simple language. The legends of creation, the rise of geology, and how the earth was made, are given in later chapters. One who reads this book will have not only the enjoyment of reading in every day readable language trustworthy information about this earth in which we live, but will also have the more lasting enjoyment of a greater interest in our landscapes and natural monuments wherever he may travel in this broad country. And the fine pictures and drawings, clear type and good paper, nicely bound in deep blue cloth, make it pleasing to handle.

ALAN BATEMAN.

Practical Oil Field Geology; 4th edition. By DORSEY HAGER. 309 pages. McGraw-Hill Co., 1926. Price $3.00.

This well-known little pocket handbook has been considerably revised and enlarged since the 1918 edition; some 55 pages and 30 figures have been added, and the value of the book thereby greatly increased. The subjects previously included deal with the properties of petroleum, geological features, geological instruments, outlining prospective oil lands, drilling, and development. The most noteworthy additions relate to oil sand porosity, the origin of oil, regional and local effects of igneous rocks on oil structures, folding, and core drilling. A brief bibliography at the end is a useful addition.

The book appears in the same pocket size with flexible binding, and bears the usual excellent McGraw-Hill craftsmanship.

A. M. B.

SOCIETY OF ECONOMIC GEOLOGISTS

The following have been declared elected to membership in the Society by the Council:

Roland Blanchard, 788 Mills Building, San Francisco, Calif.

Max Mueller Dixon, Chief Geologist, Mexican Corporation, Fresnillo, Zacaticas, Mexico.

Winthrop P. Haynes, Chief Geologist for European Interests of Standard Oil Company of N. J., 82 Ave. des Champs Elysees, Paris, France.

William F. Prouty, Professor of Geology, Univ. of North Carolina, Chapel Hill, N. C.

George M. Schwartz, Assistant Professor of Geology, Univ. of Minnesota, Minneapolis, Minn.

Joseph A. Taff, Consulting Geologist, Southern Pacific Company. Chief Geologist, Pacific & Associated Oil Cos., 79 New Montgomery St., San Francisco, Calif.

During the past year the Council has regretfully accepted the resignations of its Treasurer, J. Volney Lewis, and its Secretary, Sydney H. Ball, each forced by the pressure of work to give up the official positions which they have filled so efficiently and at much sacrifice of time. Cassius A. Fisher and Edward Sampson were appointed in November to fill the unexpired terms of, respectively, Treasurer and Secretary, and at the Council meeting on December 27, 1926, they were reappointed.

At the Madison meeting of the Society, in addition to the papers enumerated in the January–February issue of this page, there were presented the following papers in joint symposium with the Geological Society of America, and American Association of Petroleum Geologists, with President Lawson presiding:

E. DeGolyer, "Nash Salt Dome: A Study in Prospecting by Geophysical Methods" (read by title); John P. Buwalda, "Geological Features of the John Day Region, Eastern Oregon;" C. W. Tomlinson, "Pennsylvania System in the Ardmore Basin;" David R. Reger, "Pocono Stratigraphy in the Broadtop Basin of Pennsylvania;" Sidney Powers, "Age of Folding of the Wichita, Arbuckle, and Ouachita Mountains, Oklahoma;" C. L. Dake and Josiah Bridge, "Early Diastrophic Events in the Ozarks;" Myron L. Fuller and Frederick G. Clapp, "Geology of the North Shen-si Basins, China;" J. A. Udden, "Some Fossils from the Wood Formation of West Texas" (read by title); George H. Chadwick, "New Points in New York Stratigraphy" (read by title).

SCIENTIFIC NOTES AND NEWS

Percy A. Wagner has resigned from the Geological Survey of the Union of South Africa, with which organization his name has become widely known, particularly in connection with geological investigations of the remarkable South African platinum deposits, and will become geological consultant to a new mineral exploration company being formed in Johannesburg. His address in future will be P. O. Box 3185, Johannesburg, Transvaal, South Africa.

C. K. Leith, of the University of Wisconsin, lectured in February at the Army War College in Washington and at the Naval War College at Newport, Rhode Island, on "Some Consequences of the Concentration of Mineral Reserves about the North Atlantic."

Augustus Locke has been at Fierro, New Mexico, and Gilman, Colo., recently on professional business.

E. L. DeGolyer was inaugurated as president of the American Institute of Mining Engineers for the coming year at the February meeting.

Reno H. Sales, chief geologist of the Anaconda Copper Mining Company, was a recent visitor in New York.

Chester W. Washburne returned to New York February 15 from his extensive geological studies connected with petroleum in New Zealand.

D. H. Hewett, of the U. S. Geological Survey, returned to Washington early in March, after several months' field work near Goodsprings, Nevada.

L. C. Graton, professor of economic geology at Harvard University, is planning to take a sabbatical the next academic year, and will spend part of it with his family in Europe.

D. C. Barton, of the Rycade Oil Corporation, has been made chief of the magnometric and gravimetric section of the Geophysical Research Corporation, and will serve as consulting geologist to the Rycade Oil Corporation.

Arthur Wade, formerly of Australia, has established an office for consulting geological work in London.

William M. Davis and Gilbert D. Harris are lecturing this winter-spring term at the University of Arizona, and not at the University of Texas, as stated in our last issue.

E. S. Moore, professor of economic geology, University of Toronto, assisted by J. E. Maynard, is investigating conditions under which iron

and silica are precipitated under natural conditions. The laboratory study is made with special reference to the siliceous iron deposits and with the aid of a grant from the National Research Council of Canada.

Kirk Bryan, of the U. S. Geological Survey, has completed an investigation of the geology of the Avalon reservoir, Carlsbad, New Mexico, for the Bureau of Reclamation, and has returned to Cambridge, Mass.

J. B. Mertie, of the U. S. Geological Survey, will leave in May to explore geologically an unknown section of Alaska, north of the Arctic Circle and east of the Chandalar River. Gerald Fitzgerald, of the Topographic Branch, is preceding him to arrange food caches and make preliminary scouting.

H. C. Boydell, of the Department of Geology of the Massachusetts Institute of Technology, is giving a course of lectures this term on "Chemistry applied to Ore Deposition."

Louis A. Wright, of San Mateo, California, after returning from a trip to Spain and Italy, has again sailed to take up professional work in Italy.

H. DeWitt Smith has become assistant managing director of the United Verde Copper Company.

David White, K. C. Heald, and E. DeGolyer are on the Central Petroleum Committee of the National Research Council.

John M. Muir, formerly chief geologist of the Dutch Shell in Mexico, is now senior geologist for the Turkish Petroleum Company in Bagdad.

A. B. Bartlett, state geologist of Wyoming, is authority for the statement that there are two million tons of potash in southwestern Wyoming.

H. W. Hoots, of the U. S. Geological Survey, has recently written a paper on the heavy minerals of the Pliocene (Etchegoin) rocks in the San Joaquin Valley, California.

R. M. Raymond is making a sabbatical year observation tour through mining districts in South America and Europe.

Charles R. Fettke, of the Carnegie Institute of Technology, has been appointed Honorary Curator of Mineralogy at the Carnegie Museum, Pittsburgh, Pa.

H. W. Turner is now in Sonora, Mexico, engaged in mining work.

Andrew Mayer has sailed for Columbia, where he will be connected with the Cia. Minera Choco Pacifico at Andagoya.

E. E. Barker, of the Utah Copper Company, has been engaged to advise regarding the proposed open-cut working method in the Mount Morgan mine, Queensland, Australia.

W. C. Mansfield, of the U. S. Geological Survey, went to Florida in February to work in the Everglades region in co-operation with the State Geological Survey in preparation of a geologic State map.

E. C. Andrews, of Sydney, Australia, an associate editor of this journal, is expected in New Haven the latter part of April to deliver the Silliman lectures at Yale.

R. W. Brock, of the University of British Columbia, an associate editor of this journal, expects to complete his geological work at Hong Kong and return to this country in June.

J. A. Bancroft, professor of the Dawson chair of geology at McGill University, has been given a two years' leave of absence, and will join the staff of the Anglo-American Corporation of South Africa in Rhodesia.

Paul Billingsley, consulting geologist to the Anaconda Copper Mining Company and the International Smelting Company, announces general practice as consulting mining geologist at 1027 Continental Bank Building, Salt Lake City, Utah.

B. S. Butler, of the U. S. Geological Survey, lectured on February 17 to the students of the Colorado School of Mines on the subject of "The Origin of Ore Deposits with Particular Reference to the Ore Deposits of Utah."

Charles Doolittle Walcott, secretary and executive head of the Smithsonian Institution, one of the leading geologists of the world, died at Washington, D. C., on February 9, in his seventy-seventh year.

The Rock Mountain Geologists at a recent meeting held in Denver elected H. A. Stewart, of the Texas Company, president, Ross L. Heaton, vice-president, T. H. Olds, second vice-president, and R. C. Brehm, secretary and treasurer.

The recently elected officers of the Tulsa Geological Society are as follows: A. L. Beekly, president; G. C. Potter, vice-president; E. O. Markham, secretary-treasurer; W. R. Hamilton, Burr McWhirt, Constance Eirich, members of the council.

The Oklahoma Geological Survey, under the direction of Charles N. Gould, has held during the past two years a series of field conferences in Oklahoma and adjacent states, to study and correlate the geological formations of the region. More than 200 geologists have participated. The Ninth Field Conference was held February 21–23. Forty-five geologists participated. The party, under the direction of John Fitts, studied the Arbuckle Mountains formations, and visited the Bromide Springs and the "Witches' Hole." Near Atoka and Ada studies were made of the paleontology, structure and asphalt deposits, and the trip ended at the Seminole oil field.

Two other conferences are scheduled, one on March 28 and 29, following the annual meeting of the American Association of Petroleum Geologists at Tulsa, in the Arbuckle Mountains and the Ardmore Basin, to

see the porphyry monadnock known as East Timbered Hills, Turner Falls, Prices Falls, the asphalt mines, White Mound, Burning Mountain, Caddo Anticline, and Criner Hills; the other, probably in May, in the Panhandle of Oklahoma, to study conditions near the Ramsey well in Cimarron County, the volcanic rock on Black Mesa, and the Cretaceous exposures.

The Department of the Interior, U. S. Geological Survey, announced further last month that potash has been found in 26 additional wells in eight counties in Texas, and three in New Mexico, making a total of 70 wells that have now been found to contain potash, distributed in 18 counties in Texas and three counties in New Mexico.

The next International Geologic Congress, we understand, will in all probability be held in the Union of South Africa.

Another Emmons Memorial Fellowship in Economic Geology will be awarded for the next academic year. The holder of the fellowship will receive $1,000 or a little more, and is expected to carry on some worthy investigation in economic geology. Application blanks may be obtained from the Secretary of Columbia University, New York City, and must be filled out and submitted to the Committee on Awards, consisting of Professors Waldemar Lindgren and Alan M. Bateman, before April 15.

The 135th meeting of the American Institute of Mining and Metallurgical Engineers was held in New York, February 14–17. Numerous technical sessions were run simultaneously. Those of chief interest to economic geologists were the Petroleum sessions on Wednesday and Thursday, consisting of the Petroleum Economics Symposium, Round Table Discussion on Petroleum Engineering Research Problems, Refining Symposium, Production Engineering Symposium, Round Table Discussion on Petroleum Education Problems, Production Symposium, and Reviews of Petroleum for 1926. A great number of papers were read, and much lively discussion resulted, particularly in the round table discussions. Messrs. Fohs, Wrather, Pogue, Osmond, George, and Gardiner, as leaders of the discussions and presiding officers, are to be congratulated on the results achieved. At the Mining Geology session, under the chairmanship of E. F. Burchard, some eight papers were read or presented by title.

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